PROCEEDINGS

OF THE

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INCLUDING

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TRANSACTIONS

OF THE

ROYAL SOCIETY OF VICTORIA

REVISION OF SOUTHERN AUSTRALIAN CENOZOIC FOSSIL PECTINIDAE (MOLLUSCA : BIVALVIA)

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Fossil Pectinidae are revised from Paleocene to Pleistocene rocks of Western Australia, South Australia, Victoria and Tasmania (Carnarvon, Perth, Bremer, Eucla, St Vincent, Murray, Otway, Gippsland and Bass basins). They are referred to 17 genera (four newly described) and at least 55 species, of which 19 are newly described and at least 10 left unnamed. Two subfamilies are recognised: Camptonectinae, with one new Paleocene species, *Delectopecten crassistriatus*; and Pectininae, with six tribes: (1) Chlamydini, much the largest group in Australia, with 11 genera, including new genera *Abrachlamys*, *Austrohinnites* and *Dichotochlamys*, and new species *Abrachlamys toolinnensis*, *Notochlamys kendricki*, *N. nanarupensis*, *N. squamundata*, *Serripecten carteri*, *S. excultatus*, *S. squamocostatus*, *Talochlamys badioriva*, *T. laticostata*, *T. multilamellata* and *Veprichlamys leprosa*; (2) Adamussiini, containing only one species of *Victoripecten* gen. nov.; (3) Mimachlamydini, containing only six species of *Mimachlamys*, of which *M. heterophyseta* is a new Pleistocene and Recent species; (4) Decatopectinini, containing only three species of *Annachlamys*, of which *A. rhipidata* is new; (5) Palliolini, containing only *Mesopeplum*, with new species *Mesopeplum*(?) *contrainflatum*, *M. minimum* and *M. divergens*; and (6) Pectinini, containing only *Pecten* and *Amusium*, with new species *A. subcostatum* and *A. morganense*.

Nine (or possibly 10) genera and two species [*Serripecten yahliensis* (Tenison Woods), = *S. hutchinsoni* Hutton, and *Zygochlamys delicatula* Hutton] are in common with New Zealand.

The resulting new pectinid biostratigraphy will help correlate shallow-water lithologies in southern Australia. The main new results here are: (1) scallops present in Dry Creek Sands, St Vincent Basin, include *Austrohinnites polyaktinos*, *Mesopeplum subconvexum* and *Serripecten semilaevis*, demonstrating that lower Dry Creek Sands are coeval with Bookpurnong Formation (Bairnsdalian) in the Murray Basin; and (2) Mannum Formation (Longfordian, Murray Basin) contains six scallops absent from the overlying Morgan Limestone (Balcombian), whereas Morgan Limestone contains four scallops absent from Mannum Formation.

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PECTINIDS OR SCALLOPS are among the most common molluscs in Cenozoic limestones and shallow-water sandstones across southern Australia. They occur in the Carnarvon, Perth, Bremer, Eucla, St Vincent, Murray, Gambier, Otway, Port Phillip, Bass and Gippsland basins in rocks ranging in age from Paleocene to Quaternary. Potentially they could be of major utility in biostratigraphy, and the object of the present work is to investigate this possibility, as well as their evolutionary history and relationships including any trans-Tasman connections.

During the 1880s, Professor Ralph Tate of the University of Adelaide borrowed a large collection of New Zealand fossil Pectinidae from Sir James Hector, Director of the Colonial Museum and Geological Survey in Wellington, New Zealand, to compare with Tate's Australian fossils. The results of Tate's comparisons were published in 1886, as the first and only monograph, until now, of Australian Cenozoic fossil scallops. Yet most molluscan taxonomists today would say that Tate's aim was never properly realised: to study the scallops of both Australia and New Zealand, so that the faunal history and taxonomy in each country would help clarify that in the other.

Tate (1886) claimed that several taxa of fossil scallops were in common to Australia and New Zealand, even boldly stating that he could 'announce with certainty' that *Pecten* [now *Lentipecten*] *hochstetteri* Zittel occurred in both regions. The other species he thought common to the two regions was *Pecten* [now *Mesopeplum*] *polymorphoides* Zittel. However, as knowledge of molluscs has increased, opinions on such trans-Tasman relationships have changed. Marwick (1924) reconsidered the status of several pectinids (among other molluscs) that Hutton (1873), Tate (1886) and Suter (1914, 1915, 1921) had considered to be conspecific on both sides of the Tasman. He dismissed all such relationships for which he had adequate material to judge (although he was not able to examine all taxa that possibly are in common). In the present work, we list no fewer than six almost indistinguishable homeomorphs of *Lentipecten hochstetteri* in Australia and New Zealand and, unfortunately, Tate's 'certain' species in common to the two regions is no longer thought to be so. *Mesopeplum polymorphoides* probably was based on a misidentification of the New Zealand species, as well as the Australian one! And yet, in this work, we *do* recognise one mid-Cenozoic species in common to both Australia and New Zealand, one Tate did not seem to consider: *Serripecten yahliensis* (Tenison Woods) (= *hutchinsoni* Hutton); perhaps there were no specimens among the material loaned to Tate. There is also one Pleistocene species in common, *Zygochlamys delicatula* (Hutton).

Despite the long history of study of pectinids, and the unusual background of a joint Australian–New Zealand approach extending over a century, the enormous diversity of the family and the almost insurmountable hurdle of endlessly repeated homeomorphy, most of it not recognised until very recently, have meant that relationships in the Family Pectinidae in Australia and New Zealand have always been poorly understood, even mystifying. Hertlein (1969), in the 'Treatise on invertebrate paleontology' monograph of scallop genera, frankly admitted to a complete lack of knowledge of scallop phylogeny by classifying them in informal, purely morphological groups.

Understanding of scallop phylogeny has been revolutionised recently by the detailed studies of Waller (eg., 1971, 1986, 1991, 1993), which have recognised a number of 'new' characters (in the sense that no one had noticed them before!) making a huge advance towards understanding the phylogeny of the family by studying the fossil record of the evolution of these 'new', phylogenetically useful characters. Beu (1995) based a study of the common, large, biostratigraphically useful scallops in New Zealand Pliocene rocks on Waller's classification and new characters, and we build further on Waller's research here to study all known Cenozoic fossil scallops from Australia, drawn from the Carnarvon Basin in the west, south and eastward to the Gippsland Basin (the Cenozoic fossil record across southern Australia being virtually all that is known from the continent).

The Family Pectinidae probably originated in the Triassic, and the Subfamilies Camptonectinae and Chlamydinae have a long pre-Cenozoic fossil record (Waller 1991). Camptonectinae, in particular, is a mainly Mesozoic group, with only several species of *Delectopecten* lingering on in Cenozoic and Recent faunas. Some Australian Cretaceous pectinoideans have been studied by Darragh & Kendrick (1991) (seven pectinids and one species each of the families Neitheidae and Entoliidae) but we revise only the Cenozoic taxa in the present monograph.

Why study fossil scallops? The first reason is, as with most paleontological studies, simply to investigate the biodiversity. This is a large, diverse group that has been a challenge to comprehend in the past, but now we have the benefit of Waller's results to better understand their evolutionary history, with its implications for such questions as evolutionary tempo and mode, and biogeography.

The origins of the modern fauna should also be clarified.

Behind simple biodiversity, there lies the more practical needs of biostratigraphy. Once the new taxonomy and classification have been determined, our hope is that Australian Cenozoic scallops will further clarify the correlation of Australian Cenozoic rocks of shallow-water facies, particularly the extensive temperate limestones of the region.

Scallops are famous (at least, among Cenozoic macropaleontologists!) for their great utility in biostratigraphy. Their great diversity, their frequent periods of rapid evolution, and their usually excellent preservation because of their predominently calcitic mineralogy have made them one of the most useful of all molluscan groups for biostratigraphy. MacNeil (1967: 2) went so far as to claim that 'If all Tertiary stratigraphic studies were to be based on one group of molluscs and one alone, that group would undoubtedly be the pectens'. MacNeil (1967) also claimed that 'With the possible exception of the ammonites, no group of molluscs has been the subject of as many monographic studies as the Pectinidae'.

Pectinidae, we soon discovered when we started this project, are very common in Cenozoic limestone and shallow-water siliclastic sediments throughout southern Australia. We conclude below that they do, indeed, provide a surprisingly large amount of new biostratigraphic information, even at this early stage of having just determined a new revised classification. We are confident they will prove even more useful in the future for Australian Cenozoic biostratigraphy.

TAXONOMIC CRITERIA

Waller's (1991) overview of the phylogeny of commercially useful scallops made it clear why they have always been such a taxonomically 'difficult' family to study. Their overall bauplan, with two subcircular valves, a straight dorsal hingeline where the valves meet along one edge, and the single subcentral adductor muscle used (among other things) to 'clap' the valves to expel sediment—leading to the evolution of swimming to avoid predators—provides a severely limited range of options for selection to act upon. The result has been the frequently repeated evolution of only five main shell shapes, defined by Waller (1991) as:

1. *Chlamydoid*—the shape traditionally included in the form-genus '*Chlamys*', with both valves weakly inflated, a relatively tall and narrow, prosocline disc, short posterior auricles and long anterior auricles, and a deep byssal notch, a byssal fasciole and sinus, and a functional ctenolium in the byssal notch of adults. By far the most common pectinid shell form and the basis from which most other lineages have sprung, this shape reflects life attached to hard objects by the byssus, with long anterior auricles to prevent the shell rotating in the current. However, even these byssally attached scallops can release their byssus and swim away if a predator approaches.

2. *Hinnitoid*—these are irregularly growing, oyster-like scallops, cemented to a hard substrate and growing in conformity with it, and avoiding predators by growing a thick, impregnable shell. They all start life as a chlamydoid juvenile, byssally attached to the substrate, and settle down to a cemented life later, so retaining the juvenile '*Chlamys* stage' on the proximal area of the adult shell. Again, this proves to be a form-genus that has evolved many times.

3. *Aequipectinoid*—the taxa shaped like *Aequipecten*; Australian examples include *Annachlamys* and *Serripecten*. Both valves are convex (but not necessarily equally so), with a shallow byssal notch and near-equal auricles in adults, with a wide, acline to at most weakly prosocline disc shape, and generally a thick, radially sculptured shell—in many, robustly sculptured; associated with early byssal attachment, but later losing this, enabling the shell to lie freely on the seabed.

4. *Pectinoid*—the taxa shaped like *Pecten*, with the disc resembling the aequipectinoid form in outline, but with the LV flat or even slightly concave and the RV deeply convex, or bowl-shaped, with almost no byssal notch and with equal auricles. These are the taxa that burrow shallowly into the sediment, with the flat valve at the sediment-water interface, so they hide from predators, but are able to swim well if discovered (Waller 1976). This form has evolved frequently over a long period; for example, the Mesozoic pectinoid family Neitheidae contains many taxa that are good homeomorphs of *Pecten*.

5. *Amusioid*—these are the thin-shelled, light, smooth, weakly inflated scallops with almost symmetrical auricles and wide anterior and posterior shell gapes, enabling them to be much the best swimmers in the family. Swimming in the two Australian living *Amusium* species has been described by Morton (1980) (*A. pleuronectes*) and

Joll (1989) (*A. balloti*). *Amusium* is a close relative of *Pecten*, *sensu stricto*, with a smooth exterior and internal radial carinae on the interior, but several Australian and New Zealand *Amusium* homeomorphs (*Lentipecten* and similar genera) have evolved within Tribe Adamussiini and so lack internal rib carinae.

It must be stressed that these are solely descriptive terms for shell shapes, and have no relationship to taxonomy. Most classifications before Waller's have used these five shell shapes as the main generic characters; but Waller has demonstrated that the great amount of repeated homeomorphy in Pectinidae means that the gross shell shape is of very little use in phylogeny.

Shell morphology

The following section describes the characters of the pectinid shell, including the new characters that are useful in understanding phylogeny. The main morphological characters of the scallop shell are shown in Fig. 1.

Right valve (RV) and left valve (LV)

The byssus and the corresponding deep byssal notch and elongated auricle are anatomically anterior in scallops, and the hinge line is dorsal, so the valve with the deep byssal notch on the right when viewed from the exterior and with the dorsal (hinge) margin upwards is the right valve (abbreviated throughout this paper to RV) and the valve with the shallower notch (byssal sinus) is the left valve (LV).

In life, almost all pectinids lie with the RV against the substrate, because the primitive condition of byssal attachment requires the RV to rest against the attachment surface (the only apparent exception is *Juxtamusium* Iredale, 1939, which possibly may sometimes rest on the LV; Waller 1984: 216). No matter how the shell is modified, the RV of all scallops lies against the substrate. Free-lying, readily swimming, aequipectinoid and amusioid taxa lie free on the sediment on the RV; pectinoid taxa have the inflated RV buried in the substrate with the flat LV upwards; and all hinnitoid taxa are cemented by the RV. The RV is not the more inflated valve in all taxa, however; many chlamydoid and aequipectinoid taxa have the LV slightly to quite strongly more inflated than RV, and those with a strongly convex LV are aided in swimming by the airfoil effect generated by the longer cross-section of the more inflated upper surface.

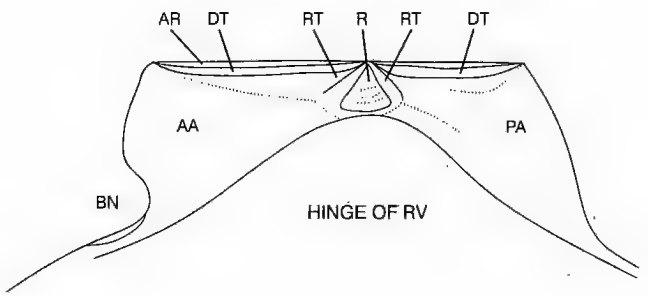
Another point to note about relative valve shape is in all pectinids that the dorsal margin of the RV overlaps the dorsal margin of the LV, providing an articulating ridge for the LV to abut against when the valves swing open. This means that the prominently serrated dorsal margin present on many scallops is located on the RV in all taxa, and that the dorsal margin of the LV is simple and straight.

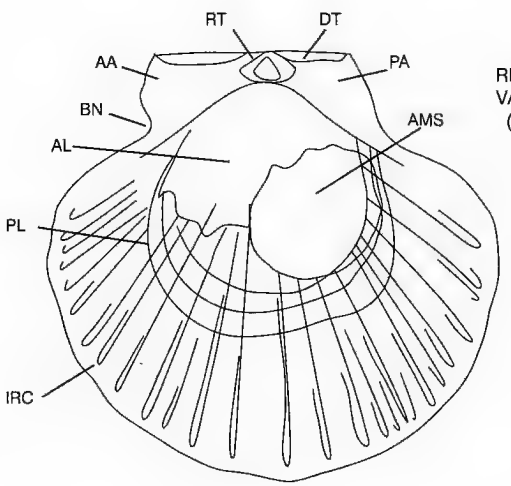
Types of sculpture: commarginal, antimarginal, radial and shagreen

The type of sculpture on the exterior of the shell provides the most obvious taxonomic characters in Pectinidae. Some of these characters are useful in phylogeny, and all are important for distinguishing species.

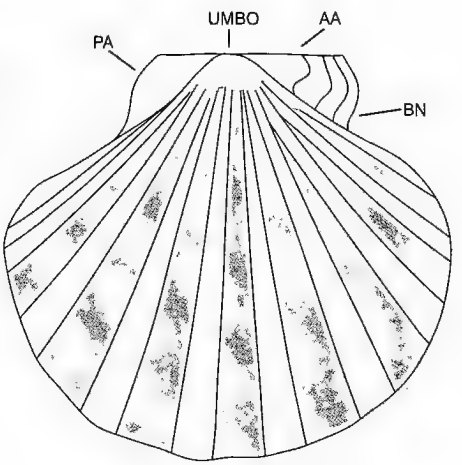
1. *Commarginal sculpture:* commarginal refers to any sculpture parallel to the valve margin, ie., produced around and parallel to the growing edge of the shell (transverse sculpture of some authors). Commarginal ridges or lamellae are common on pectinids. In Tribes Decatopectinini and Palliolini, the type of commarginal sculpture is diagnostic, and commarginal lamellae form the only microsculpture on the disc and auricles after rib inception: fine, very closely spaced commarginal lamellae in Decatopectinini and coarser, more widely spaced commarginal lamellae in Palliolini. Commarginal growth ledges (abrupt changes in disc surface topography, probably induced by sudden environmental change) also occur on some scallops, and seem to be confined to some genera; *Mesopeplum* is the only Cenozoic Australian genus in which ledges are common.

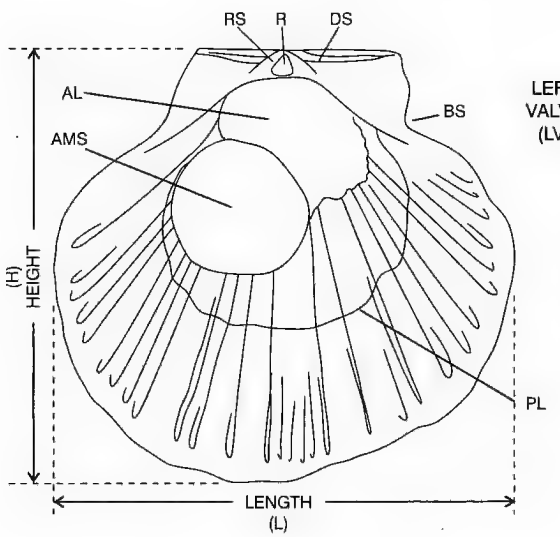
2. *Antimarginal microsculpture:* the very fine, close ridgelets found on the surface of the disc and auricles of many scallops ('*Camptonectes* microsculpture') are not strictly radial, but curve outwards towards the ends, remaining normal to the valve margin throughout growth. They are therefore parallel to the radial sculpture near the centre of the disc, but cross the radial sculpture at increasing angles toward the anterior and posterior margins of the disc. Antimarginal ridgelets are modified in a variety of ways as they meet commarginal microsculpture in many taxa, producing elaborate, distinctive microsculpture; eg., minutely frilled lamellae in *Dichotochlamys dichotomalis* and in some *Talochlamys* species (Figs 12G, 12H, 29G) and a herringbone pattern on *Mimachlamys* (Figs 45H, 46F).



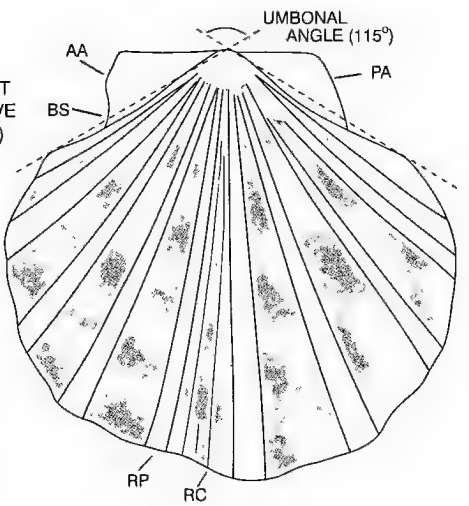


RIGHT VALVE (RV)





LEFT VALVE (LV)



3. *Radial sculpture:* the major, obvious sculpture of most scallops is radial, ie., radiating from the beaks in straight, or nearly straight, lines. Radial sculpture is normal to the valve margin near the centre of the disc, but parallel to the anterodorsal and posterodorsal valve margins, and so crossed at a high angle by the antimarginal sculpture near the ends of the disc. The most common sculpture is radial costae (ribs) and finer costellae, affecting only the outer valve surface or, in thin-shelled taxa, producing only faint radial corrugations on the interior. Many taxa also have radial plicae, major radial ridges that fold the entire valve thickness to an obvious degree, eg., *Mesopeplum*.

4. *Shagreen microsculpture:* Shagreen microsculpture consists of two sets of thin, high, diagonal lamellae, normal to the shell surface, intersecting to produce a pattern of diamond-shaped lozenges. It commonly remains only in radial interspaces, particularly on fossils, although on some very fresh, unabraded specimens it may be present on costal and plical crests as well. In many taxa, eg., *Equichlamys* and *Notochlamys*, coarse and obvious shagreen forms a secondary shell surface by producing thin outer flanges parallel to the valve surface, uniting across the lozenges to form a surprisingly smooth outer layer, but this surface is abraded off most fossils to leave only the thin ridges normal to the shell surface. Shagreen is regarded as a useful character in assessing phylogenetic relationships, as it appears to be a primitive character, found only on some members of Tribe Chlamydini.

Characters useful in phylogeny

We present here a brief overview of the shell characters newly pointed out by Waller (1986, 1991, 1993) that have been utilised by him in determination of pectinid phylogeny. The distribution of these characters in the different tribes is compared in Table 1.

1. *Radial sculpture of the disc:* In most Cenozoic and Recent Pectinidae, costae increase in number on the RV by branching or bifurcation but on the LV by intercalation in the centre of the radial interspaces. This is dictated by the interlocking of costae at the margin when the valves are closed. The most obvious character of pectinid shells for assessing relationships is the way in which radial sculpture behaves down the disc. In the most primitive tribe, Chlamydini, primary radial costae of all, or virtually all, taxa bifurcate to form secondary and finer costellae on the RV, and have secondary and finer costellae intercalated in their interspaces on the LV, irregularly down the disc. The result is that in some taxa the increasing area during growth is occupied by maintaining roughly the same relative costal width, height and spacing over the whole disc, although it may become coarser or finer down the disc in many others.

By contrast, in all the more 'advanced' Pectininae, ie., in all tribes other than Chlamydini, the primary radial costae remain fixed in number (undivided) over the whole height of the shell. In other words, the costae occupy the expanding area during growth by increasing the width (and, in many taxa, the height) of the individual costae as the shell grows, rather than by increasing in number. In many taxa (notably in the temperate *Mimachlamys* species, in Australia) secondary and finer costellae are subdivided from the edges of the primary costae, or are intercalated in the centre of the radial interspaces, but these remain low and narrow and the number of primary radial costae remains constant.

2. *Sculpture of the LV preradial dissoconch:* In almost all Pectininae, radial costae begin a short distance down the post-larval shell (the dissoconch, as opposed to the larval shell, or prodissoconch) so there is a small area, *c.* 1–2 mm high on many taxa but up to 5–8 mm high on *Pecten*, without true radial sculpture. On the RV of all scallops, this preradial area is smooth and featureless; Waller (1972b, 1991) suggested that this is because the calcite of the early RV outer layer is prismatic,

Fig. 1. Parts and dimensions of the pectinid shell referred to in this work. Based on *Equichlamys bifrons* (Lamarck), Recent, D'Entrecasteaux Channel, Tasmania, IGNS WM2021 (ex Suter Coll.; 2 unmatched valves). Length is measured parallel to the hinge line; height is measured normal to the hinge line. *Abbreviations:* **AA**, anterior auricle; **AL**, foliated calcite re-entry in umbonal region, covering aragonite layer (which makes up internal surface ventral to AR, inside pallial line); **AMS**, adductor muscle scar; **AR**, outer-ligament insertion groove, bordered above by abutting ridge (narrow dorsal ridge in RV, against which LV abuts when opened); **BN**, byssal notch, in RV; **BS**, byssal sinus, in LV; **DS**, dorsal (hinge) socket; **DT**, dorsal tooth; **IRC**, internal rib carina; **PA**, posterior auricle; **PL**, pallial line; **R**, resilifer; **RC**, radial costa; **RP**, radial plica; **RS**, resilial socket; **RT**, resilial tooth.

and consequently not able readily to develop fine, sharp sculpture, whereas the calcitic outer layer on the LV has a foliated structure, and can develop fine sculpture. On the LV preradial area, microsculpture is present so that, at least in many taxa, this can be a valuable guide to phylogenetic relationships. This sculpture can be examined by binocular microscope at *c.* ×50 enlargement, but is more easily studied and illustrated by SEM. Many such SEM studies are illustrated in this paper. The one exception we are aware of is the living tropical Pacific species '*Chlamys*' *coruscans* (Hinds, 1845), which has no prismatic calcite outer layer on the early RV, and has radial costae commencing at the prodissoconch–dissoconch boundary (Waller 1972a: 233).

Many specimens (particularly fossils) lack this fine sculpture because of abrasion, and the calcite layer of the early disc is so thin that a small amount of abrasion reveals the aragonite myostracum in the umbonal area (which, because the aragonite dissolves away easily, leaves only a hole in the umbonal area of many specimens), so a search for suitable specimens for the study of this character has been an important aspect of the present research. However, many Australian fossil scallops from soft, fine-grained rocks have exquisitely preserved microsculpture over the whole exterior, so that one of the reasons for studying Australian scallops before those from New Zealand is ready access to the phylogenetic information available from these beautifully preserved specimens, but absent on almost all from New Zealand.

The most primitive LV preradial sculpture is simple antimarginal ridgelets. Among Australian taxa, this sculpture is seen on *Serripecten* (Fig. 24B, D) and on *Zygochlamys delicatula* (Hutton) (Fig. 43C, E). Most other primitive chlamydinines have the antimarginal ridgelets broken up by commarginal ridges of varying prominence, to form a fenestrate, or reticulate, pattern of alternating commarginal ridges and commarginal zones of short antimarginal ridgelets. In many other chlamydinines, the sculpture becomes much weaker, so the hollows (pits) between the antimarginal ridgelets become the most obvious or the sole remaining, very faint sculpture on an otherwise smooth preradial area. We have little knowledge of the 'preradial' sculpture of the early LV disc of members of Tribe Adamussiini.

In *Mimachlamys asperrima* (Lamarck), a quite different, distinctive LV preradial sculpture is present, consisting of shallow, oval, irregularly

Tribe	Radial costae	LV preradial microsculpture	Internal rib carinae	Disc microsculpture	Hinge teeth
CHLAMYDINAE					
Chlamydini	subdivided and intercalated	antimarginal ridgelets	absent (except *Notochlamys* and *Equichlamys*)	antimarginal ridgelets; shagreen	resilial and dorsal
Adamussiini	absent; or weak, late-starting, discrepant	antimarginal ridgelets	absent	antimarginal ridgelets	resilial and dorsal
Mimachlamydini	undivided	shallow pits	present in most	herringbone pattern	resilial and dorsal
Aequipectinini	undivided	large, deep pits	present	commarginal lamellae curved towards venter on rib flanks	enlarged resilial
PECTININAE					
Decatopectinini	undivided	weak elongate pits	present	very close commarginal lamellae	dorsal and intermediate
Palliolini	undivided	commarginal and antimarginal ridgelets	present	widely spaced commarginal lamellae	dorsal
Pectinini	undivided	smooth; LV preradial area large	present	widely spaced commarginal lamellae	dorsal and intermediate

Table 1. Distribution of phylogenetically important characters among the main tribes of Pectinidae. (Tribe Aequipectinini does not occur in Australia.)

arranged but evenly spaced pits in an otherwise smooth background. Similar pits are present on all other present-day *Mimachlamys* species. The fossil history of *Mimachlamys* in Australia (*M. sturtiana* Tate) shows that these pits evolved by weakening (as if 'sinking into the background') of an original sculpture of combined commarginal and antimarginal ridges.

Tribe Aequipectinini (not present in Australia) is characterised by LV preradial sculpture of obvious, large, deep, almost hemispherical pits, leaving a raised, even, smooth, net-like surface between the pits.

Tribe Decatopectinini (including only *Annachlamys* as a fossil in Australia) is characterised by extremely weak LV preradial sculpture of very shallow, faint, irregularly arranged, antimarginally orientated pits, similar to that of many Chlamydini.

In contrast, Tribe Palliolini (including only *Mesopeplum* as a fossil in Australia) is characterised by prominent LV preradial sculpture of fenestrate, well raised commarginal and antimarginal ridges, leaving roughly rectangular pits between them and, in some species, with minute nodules at the sculptural intersections. The antimarginal ridges fade out rapidly after costal inception, and are not present on the adult disc or auricles of any Palliolini, which bear only widely spaced commarginal lamellae.

Tribe Pectinini, containing the most advanced scallops, has a LV preradial area that is almost smooth or, in many taxa (including *Pecten*), completely smooth. Some taxa have faint, shallow, elongate, antimarginally orientated pits as in Decatopectinini, but a large, smooth preradial area, 5 to 8 mm high, is visible to the naked eye on *Pecten*.

3. *Internal rib carinae:* Another prominent, very useful character in determining or recognising phylogeny is the presence or absence of internal rib carinae. These are narrow, sharp, thickened ridges along the two edges of the internal expression of the external costae or plicae, helping to interlock the ventral margins of the valves. Internal rib carinae are absent from virtually all Chlamydini and Adamussiini, and are present on almost all other Pectininae. The only exceptions to this are the Australian taxa *Equichlamys bifrons* (Lamarck) and the two youngest species of *Notochlamys*, *N. hexactes* (Lamarck) and *N. kendricki* sp. nov. These are unusual, shagreen-bearing Chlamydini that independently have evolved internal rib carinae. Similarly, most tropical, thick-shelled *Mimachlamys* species have simple, coarse, undivided external costae and prominent internal rib carinae, whereas the more thin-shelled, narrowly costate, Australian temperate species *M. asperrima* (type species of *Mimachlamys*) and *M. heterophyseta* sp. nov. lack internal rib carinae, or have only short, weak ones around the valve margin (in some large *M. asperrima*, and in particular, in a few thick-shelled specimens of *M. heterophyseta*). These are the only exceptions known to us from Australia to the internal carinae principle.

4. *Disc microsculpture:* As noted under *Types of sculpture*, above, the orientation of the microsculpture on the disc after costal inception can be of great phylogenetic significance. Shagreen microsculpture and normal, unmodified antimarginal ridgelets on the disc are both primitive characters, found only in Chlamydini. Mimachlamydini are characterised by (among other things) microsculpture of an irregular herringbone pattern in the intercostal spaces. Aequipectinini are characterised by (among other things) commarginal ridges with a prominent flexure convex towards the venter, in the intercostal spaces. Most distinctive of all is the microsculpture of Palliolini and Decatopectinini, which lack antimarginal ridgelets after costal inception and have regularly spaced commarginal lamellae in intercostal spaces and, on unabraded specimens of most taxa, on costal crests as well, apart from most species of *Palliolium*, in which the commarginal sculpture is weakly developed (H. H. Dijkstra, pers. comm.). The lamellae are very fine and closely spaced (about 30–70 per 2 mm interval, in the centre of the disc, 10 mm from the umbo) in Decatopectinini, and much more widely spaced, easily visible to the naked eye (about 5–15 per 2 mm interval, in the centre of the disc, 10 mm from the umbo) in Palliolini—in Australia, the genus *Mesopeplum*.

5. *Hinge teeth:* Waller (1991: 8, fig. 6) proposed new terms for the hinge teeth of pectinids, treating them for the first time as phylogenetically useful characters like those, for example, of the heterodont family Veneridae. Chlamydini, Adamussiini and Mimachlamydini have only two long, narrow teeth parallel to the hinge margin, both anterior and posterior to the resilifer, in the RV (*dorsal* teeth), with a thin tooth above (*supradorsal* teeth) and another below (*infradorsal* teeth) flanking the sockets for the dorsal teeth in the LV; and two *resilial* teeth, one along each edge of the resilifer in the RV, and corresponding sockets in the LV. Thus the dominance of dorsal and resilial hinge teeth is considered to be another primitive character of the Pectininae. In the more advanced tribes

Palliolini, Decatopectinini and Pectinini the resilial teeth are not present, or at most are very weak, and *intermediate* teeth are present below the dorsal and infradorsal teeth. The intermediate teeth become obvious, major characters of the hinge in some taxa, notably in *Decatopecten* and, above all, in *Pecten*, which has numerous, narrow, prominent dorsal and intermediate teeth radiating from the dorsal apex of the resilifer. In many Australian fossil taxa the hinge teeth are low and narrow, and so difficult to use with confidence as a phylogenetic character, although they agree with the outlines of the classification proposed by Waller (1991, 1993).

CLASSIFICATION

In this work, we follow the classification of Pectinidae proposed by Waller (1986, 1991, 1993) and by Waller & Marincovich (1992) in which *Delectopecten* is the only Cenozoic and Recent member of the otherwise Mesozoic subfamily Camptonectinae, and all other post-Cretaceous scallops belong in subfamily Pectininae. The Australian Cenozoic Pectininae belong in six tribes.

Waller (1991, 1993) recognised three subfamilies of Cenozoic and living Pectinidae, the subfamily Camptonectinae recognised here, plus subfamily Chlamydinae, including tribes Chlamydini, Crassadomini, Mimachlamydini and Aequipectinini, and subfamily Pectininae, including tribes Decatopectinini, Palliolini and Pectinini. In this scheme the newly recognised tribe Adamussiini would belong in Chlamydinae. Dr Waller has since advised us that this classification no longer is tenable. An alternative classification (Frischer et al. 1998) is based on the demonstration from gene sequences that *Argopecten* Monterosato, 1899 (Aequipectinini) is more closely related to Pecten Müller, 1776 than are *Chlamys* Röding, 1798 (Chlamydini), *Mimachlamys* Iredale, 1929 (Mimachlamydini), *Crassadoma* Bernard, 1986 (Crassadomini) and *Placopecten* Verrill, 1897 (Palliolini). This suggests that a subfamily Pectininae should be recognised to include only tribes Pectinini and Aequipectinini, whereas all other tribes, except those of the Camptonectinae, should be placed in a subfamily Chlamydinae. The position of Decatopectinini in this classification is not yet determined, however, and we adopt a single subfamily Pectininae here, on the advice of Dr Waller. Likewise, a further tribe of Pectininae, Adamussiini Habe, 1977, is recognised here, to contain the Australian and New Zealand superficially smooth, *Amusium*-like genera, lacking internal rib carinae and related to *Lentipecten* Marwick, 1928. The tribe apparently contains also the Antarctic living and Early Pliocene (Jonkers 1998) species of *Adamussium* Thiele, 1934, and their presumed Oligocene–Miocene ancestor(s).

Since this paper was submitted for publication, Matsumoto & Hayami (2000) published an important contribution to pectinid phylogeny, based on analysis of mitochondrial cytochrome *c* oxidase subunit I. This work provides very strong support for the subdivision of living scallops (apart from Subfamily Camptonectinae) into the two subfamilies Chlamydinae and Pectininae, as suggested by Waller (1991). Matsumoto & Hayami (2000: 485) considered that their results are more informative and less conservative than the 18S rRNA analysis by Frischer et al. (1998). It is now clear that Waller's (1991) original classification into two subfamilies was correct.

1. *Tribe Chlamydini:* Pectininae with a primitive sculpture of antimarginal ridgelets present from the edge of the prodissoconch on the LV and from the edge of the proximal calcite area on the RV, but variously modified by intersection with commarginal ridges in many genera; with small posterior auricles with a weakly concave posterior outline, at least in primitive lineages; most taxa retaining much larger anterior auricles than the posterior ones into adulthood and retaining a deep byssal notch in the RV, although some large-sized taxa (eg., *Equichlamys bifrons*, '*Zygochlamys*' *delicatula*) become free-lying during growth, lose the ctenolium and develop a shallow byssal notch; with complexly subdivided and intercalated radial costae, increasing in number as the shell grows; without prominent, narrow carinae on the edges of the interior expressions of the radial corrugations (except in *Equichlamys* bifrons and the two youngest species assigned to *Notochlamys*, where they seem to have evolved independently of the carinae in other scallops); with simple and, in most taxa, low and narrow resilial and dorsal hinge teeth; and with shagreen microsculpture, at least in primitive lineages and on the proximal disc of many Cenozoic and living taxa. The tribe includes all scallops with shagreen microsculpture, although by no means all Chlamydini have shagreen. This is much the largest group of Australian fossil scallops.

2. *Tribe Adamussiini Habe, 1977:* This tribe is recognised newly (with name adopted from Adamussiinae Habe, 1977: 75, as 'Adamussinae') for the *Lentipecten*-like pectinid taxa of New Zealand, Australia and Antarctica. Dr T. R. Waller (1999, pers. comm.) has pointed out that these taxa

are united not only by their moderate size, their weak inflation, their almost circular disc, their lack of obvious radial sculpture on the disc, the presence of fine antimarginal striae at least on the anterodorsal and posterodorsal areas of the disc and on the auricles, their almost equal auricles, their shallow byssal notch in adults but deeper byssal notch and, in many taxa, a functional ctenolium in juveniles (characters found in a large number of superficially similar pectinids, world-wide) but also by the narrow radial costae on the RV anterior auricle in many taxa, by their serrate RV dorsal margins, and by their very obvious, widely separated gill suspensor muscle scars ventral to the adductor scar in the interior of the RV (see in *Victoripecten victoriensis*, Fig. 43E). Most included genera also have radial sculpture, which if present, appears relatively late in ontogeny and, in several taxa, is expressed differently on each valve.

Beu & Dell (1989) recognised a species they referred to *Adamussium* Thiele, 1934 from Oligocene rocks in the CIROS-1 drillhole, Ross Sea, Antarctica, suggesting that this made a plausible ancestor for the living and Early Pliocene (Jonkers 1998) weakly radially plicate Antarctic pectinid *Adamussium colbecki* (E. A. Smith 1902). This species has since been found in some numbers in Oligocene rocks in the CRP-2 drillhole, also in the Ross Sea (Taviani et al. 2000). Endorsement of this apparent relationship with *A. colbecki* has been expressed to us by both Dr H. Jonkers and Dr Waller. *Adamussium colbecki* shares almost all the distinctive characters listed above with *Lentipecten* and *Victoripecten*, and we judge it likely that *A. colbecki* is a member of this tribe that has developed radial plicae late in its phylogenetic history. We therefore tentatively adopt the tribe name Adamussiini for this southern group of Pectinidae, rather than propose a new one that might eventually prove to be synonymous. Genera included in tribe Adamussiini are *Adamussium* Thiele, 1934, *Lentipecten* Marwick, 1928 (= *Janupecten* Marwick, 1928), the Oligocene–Miocene unnamed '*Lentipecten*' *homeomorph* reported by Maxwell (in Beu & Maxwell 1990: 145), *Victoripecten* gen. nov., and a possibly distinct, unnamed genus from Early–Middle Eocene rocks in New Zealand (this genus(?) might also be based on an early species of *Victoripecten*; see discussion in the taxonomic section, below). Recently the European Eocene species *Pseudentolium corneum* (J. Sowerby, 1818) has been placed in *Lentipecten* (following Hertlein 1969: N349). However, Dr Waller (1999, pers. comm.) has informed us that this species lacks several of the distinctive characters of *Lentipecten*, most obviously the prominent gill-suspensor muscle scars in the RV, and it is clear that *Pseudentolium* Cox (1948: 63) not only is a genus distinct from *Lentipecten*, but also belongs in a different tribe.

3. *Tribe Mimachlamydini:* Pectininae with the LV preradial dissoconch sculptured with shallow pits (in living taxa) or with the pits outlined by intersecting commarginal ridgelets and antimarginal ridgelets (in the Australian fossil species); of chlamydoid shape, with small posterior auricles and long anterior auricles, retaining a deep byssal notch and a functional ctenolium in adults of almost all taxa; with simple primary sculpture of undivided radial costae, fixed in number throughout growth, although secondary and tertiary costellae subdivide from the costal edges to form a fasciculate rib profile in some species (including the type species of *Mimachlamys*); with internal rib carinae on the costal edges of most taxa, although weak or absent in a few; with intercostal microsculpture of highly modified ridgelets, in most taxa in a divaricating or herringbone pattern, not strictly antimarginal or commarginal in any taxa; and with the hinge dominated by dorsal and resilial teeth. Among Australian fossils, the tribe contains only *Mimachlamys*.

4. *Tribe Decatopectinini:* Pectininae with LV preradial dissoconch microsculpture consisting only of very weak, antimarginally elongate pits; with microsculpture after costal inception of very closely spaced commarginal lamellae, at least early in ontogeny and, in many taxa, throughout life, spaced at *c.* 30–70 per 2 mm interval in the centre of the disc at 10 mm from umbo; with a very weakly inflated to almost flat LV umbo, which therefore extends only very slightly above the hingeline; with antimarginal ridgelets very fine and restricted to the preradial disc, not present on auricles or on disc flanks; with a fixed number of undivided radial costae throughout life; with prominent internal rib carinae; and with the hinge dominated by dorsal and intermediate teeth, resilial teeth low or absent, intermediate teeth numerous and prominent in several genera (notably *Decatopecten*). Among Australian fossils, the tribe contains only *Annachlamys*.

5. *Tribe Palliolini:* Pectininae with LV preradial dissoconch sculpture in most taxa of prominent commarginal ridges crossing the antimarginal ridgelets; most members with reduced resilial teeth, the dorsal teeth the most prominent; many members with internal coarse and, in Recent specimens, highly reflective patches of uniformly oriented

calcite laths outside the pallial line; with a delicate ctenolium with small, closely spaced teeth; with the byssal notch and sinus fairly shallow throughout ontogeny, and not functional in adults of many taxa; with dissoconch microsculpture, after costal inception, of simple, widely spaced commarginal ridges or lamellae, 5–15 per 2 mm interval on the centre of the disc 10 mm from the umbo; and with, at least in all the more advanced taxa, prominent internal rib carinae, although some primitive taxa are non-carinate. Among Australian fossils, the tribe contains only *Mesopeplum*.

6. *Tribe Pectinini:* Pectininae with LV preradial dissoconch nearly or completely smooth, very small pits present on a few taxa; LV preradial area and RV prismatic calcite proximal area extending much further from umbo than in any other Pectinidae, up to 5 mm high in many taxa, clearly visible to the naked eye on *Pecten* as a smooth umbonal area up to 8 mm high; radial costae fixed in number throughout ontogeny, weakly subdivided by narrow secondary grooves in some taxa; internal rib carinae prominent in all taxa, including those that have lost the external costae (eg., *Amusium*); hinge teeth prominent, numerous in many taxa, predominantly dorsal and intermediate teeth, resilial teeth present in very few taxa. Among Australian fossils, the tribe contains only *Amusium* and *Pecten*.

SYSTEMATIC LIST OF AUSTRALIAN CENOZOIC PECTINIDAE

Subfamily **Camptonectinae**

Delectopecten Stewart, 1930
- *Delectopecten crassistriatus* sp. nov., Paleocene, Otway Basin

Subfamily **Pectininae**

Tribe Chlamydini

Abrachlamys gen. nov.
- *Abrachlamys toolinnensis* sp. nov., Early Miocene, Eucla Basin

Austrohinnites gen. nov.
- *Austrohinnites corioensis* (McCoy, 1879), Late Oligocene–Late Miocene, Murray, Port Phillip, Gippsland and Bass basins
- *Austrohinnites polyaktinos* (Ludbrook, 1955), Middle Miocene, St Vincent and Murray basins

Dichotochlamys gen. nov.
- *Dichotochlamys dichotomalis* (Tate, 1886), Middle Miocene, Murray and Port Phillip basins

Equichlamys Iredale, 1929
- *Equichlamys bifrons* (Lamarck, 1819), Late Pliocene to Recent, southern, but not Western Australia

Notochlamys Cotton, 1930
- *Notochlamys*(?) *nanarupensis* sp. nov., Late Eocene, Bremer Basin
- *Notochlamys*(?) *squamundata* sp. nov., Late Oligocene–Early Miocene, Eucla, St Vincent and Port Phillip basins
- *Notochlamys kendricki* sp. nov., Late Pliocene, Eucla Basin

Semipallium Jousseaume in Lamy, 1928
- *Semipallium foulcheri* (Tenison Woods, 1865), Early Oligocene–Middle Miocene, throughout southern Australia, north to Carnarvon Basin
- *Semipallium aktinos* (Petterd, 1886), Early Pleistocene, Perth Basin; Recent, around most or all of Australia

Serripecten Marwick, 1928
- *Serripecten aldingensis* (Tate, 1886), Late Eocene, Bremer and St Vincent basins
- *Serripecten excultatus* sp. nov., Late Eocene, Otway Basin
- *Serripecten* sp. nov., Late Oligocene, Otway and Port Phillip basins
- *Serripecten squamocostatus* sp. nov., Early Miocene, St Vincent, Murray, and Otway basins
- *Serripecten yahliensis* (Tenison Woods, 1865) (= *hutchinsoni* Hutton), Early Miocene to Late Miocene, St Vincent, Murray, Otway, Port Phillip, Bass and Gippsland basins; New Zealand
- *Serripecten semilaevis* (McCoy, 1876), Middle (and Late?) Miocene, St Vincent, Murray, Port Phillip and Gippsland basins
- *Serripecten carteri* sp. nov., Late Miocene, Port Phillip and Gippsland basins

Talochlamys Iredale, 1929
- *Talochlamys badioriva* sp. nov., Late Eocene, Bremer, St Vincent and Otway basins
- *Talochlamys*(?) sp. nov. A, Late Eocene, Eucla Basin
- *Talochlamys*(?) sp. nov. B, Late Eocene, Bremer Basin
- *Talochlamys*(?) *eyrei* (Tate, 1886), Late Eocene–Early Miocene, St Vincent, Murray and Port Phillip basins
- *Talochlamys multilamellata* sp. nov., Early Miocene, Eucla Basin
- *Talochlamys*(?) sp. nov. C, Early Miocene, Eucla Basin
- *Talochlamys*(?) sp. nov. D, Early or Middle Miocene, Eucla Basin
- *Talochlamys*(?) spp. nov., Middle Miocene, Port Phillip Basin

Talochlamys laticostata sp. nov., Middle Miocene, Murray Basin
Talochlamys keiloriana (Crespin, 1926), Middle and Late Miocene, Port Phillip and Gippsland basins
Veprichlamys Iredale, 1929
Veprichlamys leprosa sp. nov., Middle Miocene, Port Phillip Basin
Zygochlamys Ihering, 1907
Zygochlamys delicatula (Hutton, 1873), Late Pleistocene, shelf off Tasmania–southern New South Wales [and Late Pliocene–Recent, New Zealand]

Tribe Adamussiini
Victoripecten gen. nov.
Victoripecten victoriensis (Crespin, 1950), Late Eocene–Early Miocene, Eucla, St Vincent, Murray, Otway, Port Phillip, Gippsland and Bass basins

Tribe Mimachlamydini
Mimachlamys Iredale, 1929
Mimachlamys sp. nov.(?), Late Eocene, St Vincent Basin
Mimachlamys sturtiana (Tate, 1886), Late Oligocene–late Middle Miocene, St Vincent, Murray, Otway and Port Phillip basins
Mimachlamys asperrima (Lamarck, 1819), late Middle Miocene–Recent, throughout southern Australia
Mimachlamys heterophyseta sp. nov., Early to late Middle Pleistocene, Perth and Bass basins; Recent, south-western Western Australia
Mimachlamys funebris (Reeve, 1853), Late Pleistocene and Recent, Western Australia
Mimachlamys sp. nov., 'Shark Bay'; Late Pleistocene and Recent, Western Australia

Tribe Decatopectinini
Annachlamys Iredale, 1929
Annachlamys rhipidata sp. nov., Late Oligocene–Early Miocene, Murray and Port Phillip basins
Annachlamys murrayana (Tate, 1886), late Early and Middle Miocene, Eucla, Murray, Port Phillip and Gippsland basins
Annachlamys sp. nov.?, Early Miocene, Eucla Basin; Middle Miocene, Carnarvon Basin

Tribe Palliolini
Mesopeplum Iredale, 1929
Mesopeplum gambierense (Tenison Woods, 1865), Early Miocene, Otway Basin
Mesopeplum minimum sp. nov. Early Miocene, Murray and Port Phillip basins
Mesopeplum incertum (Tenison Woods, 1865), Middle Miocene, Murray and Port Phillip basins
Mesopeplum subconvexum (Tate, 1887), late Middle and Late Miocene, St Vincent, Murray, Otway and Gippsland basins
Mesopeplum(?) *contrainflatum* sp. nov., Late Miocene, Gippsland Basin
Mesopeplum divergens sp. nov., Late Miocene, Port Phillip and Gippsland basins
Mesopeplum meringae (Tate, 1899), Late Miocene and Pliocene, Gippsland and Bass basins
Mesopeplum fenestratum (Hedley, 1901), Late Miocene, Gippsland Basin [aff. *fenestratum*] and Recent, throughout southern Australia

Tribe Pectinini
Amusium Röding, 1798
Amusium subcostatum sp. nov., Late Oligocene–Early Miocene, Murray and Port Phillip basins
Amusium morganense sp. nov., Middle Miocene, Eucla and Murray basins
Amusium balloti (Bernardi, 1861), Middle Miocene(?)–Pliocene, Perth, St Vincent, Murray and Gippsland basins; Recent, tropical Pacific, south to southern Western Australia and southern New South Wales
Pecten Müller, 1776
Pecten fumatus Reeve, 1852, Pleistocene–Recent, throughout southern Australia

Pectinidae, not identified
A; Middle Miocene, Eucla Basin
B; Middle Miocene, Eucla Basin

This fauna consists of 17 genera and at least 55 species, of which four genera and 19 species are newly named below, and at least 10 species are left unnamed.

BIOGEOGRAPHY AND EVOLUTION

Trans-Tasman relationships

The main impetus for us to undertake this work together was the perceived similarities between the pectinids of Australia and New Zealand. It has been clear since the monographs of Tate (1886) and Marwick (1928) that at least *Serripecten*, *Mesopeplum*, '*Hinnites*', *Pecten* and a genus (or genera?) resembling *Lentipecten* occurred on both sides of the Tasman Sea. It seemed likely that detailed comparison of the two faunas would bring to light further taxa in common, and clarify the history of the pectinid faunas in both regions. We did, indeed, find that two species are common to Australia and New Zealand—*Serripecten yahliensis* (Tenison Woods) and *Zygochlamys delicatula*

(Huton)—but have recognised surprisingly few other close relationships. The differences between the faunas are as striking as the similarities, and presumably each has as much to say as the other about the history of the two faunas. Here we briefly review the faunal similarities and differences, and consider possible reasons for these, as well as evidence for evolution in the fossil record of southern Australian scallops.

Taxa common to Australia and New Zealand

We conclude that the pectinid taxa common to Australia and New Zealand are: (1) the two species *Serripecten yahliensis* (Tenison Woods) [= *S. hutchinsoni* (Hutton)] and *Zygochlamys delicatula* (Hutton); and (2) the nine genera *Delectopecten* Stewart, 1930 [Recent only, in New Zealand], *Austrohinnites* gen. nov., probably *Dichotochlamys* gen. nov. (it is not quite certain that the unnamed New Zealand Oligocene and Miocene species are congeneric with the Australian *D. dichotomalis*), *Serripecten* Marwick, 1928, *Talochlamys* Iredale, 1929, *Veprichlamys* Iredale, 1929 [Recent only, in New Zealand], *Zygochlamys* Ihering, 1907, *Mesopeplum* Iredale, 1929, and *Pecten* Müller, 1776. It is also a plausible hypothesis that an ancestral species of a tenth genus, *Victoripecten* gen. nov., occurs in New Zealand Middle Eocene rocks, but this remains inconclusive, because of the very high degree of homeomorphy in these smooth, rather featureless shells.

Origins and extinctions

The scallop faunas of Australia and New Zealand can be divided into six groups of genera, according to their apparent arrival times (ie., times of earliest appearance in the stratigraphic record), their geographic ranges and their extinction times. The six groups are reviewed below:

1. *Genera in common:* The nine (or perhaps 10) genera common to both Australia and New Zealand are listed above. Most have early to middle Cenozoic (Eocene to Early Miocene) first appearances in the region, with *Pecten* and *Zygochlamys* appearing much more recently, and are discussed below in the sixth group of Pleistocene arrivals. Also, both *Delectopecten* (although known only from the Paleocene Pebble Point Formation) and *Veprichlamys* (Middle Miocene) have a fossil record in Australia, but in New Zealand are recorded only in the living fauna. Of the early-appearing genera, *Austrohinnites*, *Dichotochlamys* (probably an Australasian side-branch from *Talochlamys*) and *Serripecten* became extinct in both regions at about the end of Middle Miocene time or during the Late Miocene. In contrast, the other early-appearing genera (ie., not including *Zygochlamys* and *Pecten*) still live on both sides of the Tasman Sea, and successfully adapted to post-Miocene oceanic cooling (*Delectopecten*, *Talochlamys*, *Veprichlamys* and *Mesopeplum*). However, *Mesopeplum* is the only one of these that is a restricted, Australasian endemic genus still living in both regions (although even this possibly occurs in Argentina; see under *Mesopeplum*, below). *Delectopecten* is cosmopolitan in the deep sea (Grau 1959) and so may not have been affected greatly by temperature change; *Veprichlamys* is widespread in the Indo-West Pacific and eastern Pacific provinces (Waller 1993); and *Talochlamys* appears to be a widespread temperate Southern Hemisphere genus.

2. *Early genera limited to Australia:* Five genera first appeared in Australia during Eocene or Oligocene time, but in most cases *have never reached New Zealand* (*Notochlamys*, *Semipallium*, *Mimachlamys*, *Annachlamys* and *Amusium*; *Victoripecten* is assumed here to have originated in New Zealand). Except for two Recent species, *Notochlamys hexactes* (Lamarck) and *Semipallium aktinos* (Petterd), these are predominantly warm-water taxa, persisting in the tropical north of Australia and throughout the Indo-West Pacific Province (although, of course, *Mimachlamys asperrima* occurs in cool to temperate, southern Australian waters). These early-appearing, restricted, Australian warm-water genera, which occurred here during the period of warm-temperate to subtropical Cenozoic sea temperatures, all had the tropical waters northern Australia available as refugia. *Semipallium aktinos* apparently has the distinction of living around most of the Australian coast, a highly unusual range for an apparently endemic Australian species. This leaves only one Australian restricted, endemic genus before Pliocene time, *Abrachlamys* gen. nov., other than the possible case of *Notochlamys*. We can make little of *Abrachlamys* at present, as we know only the single Early Miocene species from the Eucla Basin. But, as noted under *Abrachlamys* below, Dr T. R. Waller has pointed out to us that several European fossil species resemble *A. toolinnensis* sp. nov. and may be related to it phylogenetically. Initially we considered that no New Zealand species was referable to *Mimachlamys*, but Dr Waller has pointed out (1999, pers. comm.) that the *Chlamys*

chathamensis (Hutton) species group in New Zealand has undivided primary costae and herringbone-pattern microsculpture, and appears to belong in *Mimachlamys* (earliest species: '*Chlamys*' sp. of Maxwell 1992: pl. 3g–i, Late Eocene; last record: '*Chlamys*' sp., Momoe-a-toa Shellbed, Chatham Island, basal Pliocene).

Notochlamys is in some ways in a category all by itself, as it is the one clear example we are aware of, of an early-appearing, restricted, Australian endemic genus that remains extant; however, it might not be an exception to the above category at all. The Late Eocene to Early Miocene species included here in *Notochlamys* (*N. nanarupensis* sp. nov., Bremer Basin; and *N. squamundata* sp. nov., Eucla, St Vincent and Port Phillip basins) provide plausible early members of the genus, but the specimens to hand are not well enough preserved to show the characters critical for understanding phylogeny. On the available evidence, this is possibly yet another case of homeomorphy. Undoubted *Notochlamys*, with internal rib carinae and prominent, sharply defined plicae, is first recorded in the fossil record as *N. kendricki* sp. nov., from the Late Pliocene Roe Calcarenite of the Eucla Basin. The earlier species certainly resemble the younger species of *Notochlamys* more closely than they do any other Australian genus, so for the present this is their most appropriate position. An equally plausible hypothesis, though, is that these belong in another genus, with *Notochlamys sensu stricto* descended from *Swiftopecten*, and arriving in Australia during Pliocene time, perhaps via the Argentinian Miocene species of *Swiftopecten* (del Rio 1995).

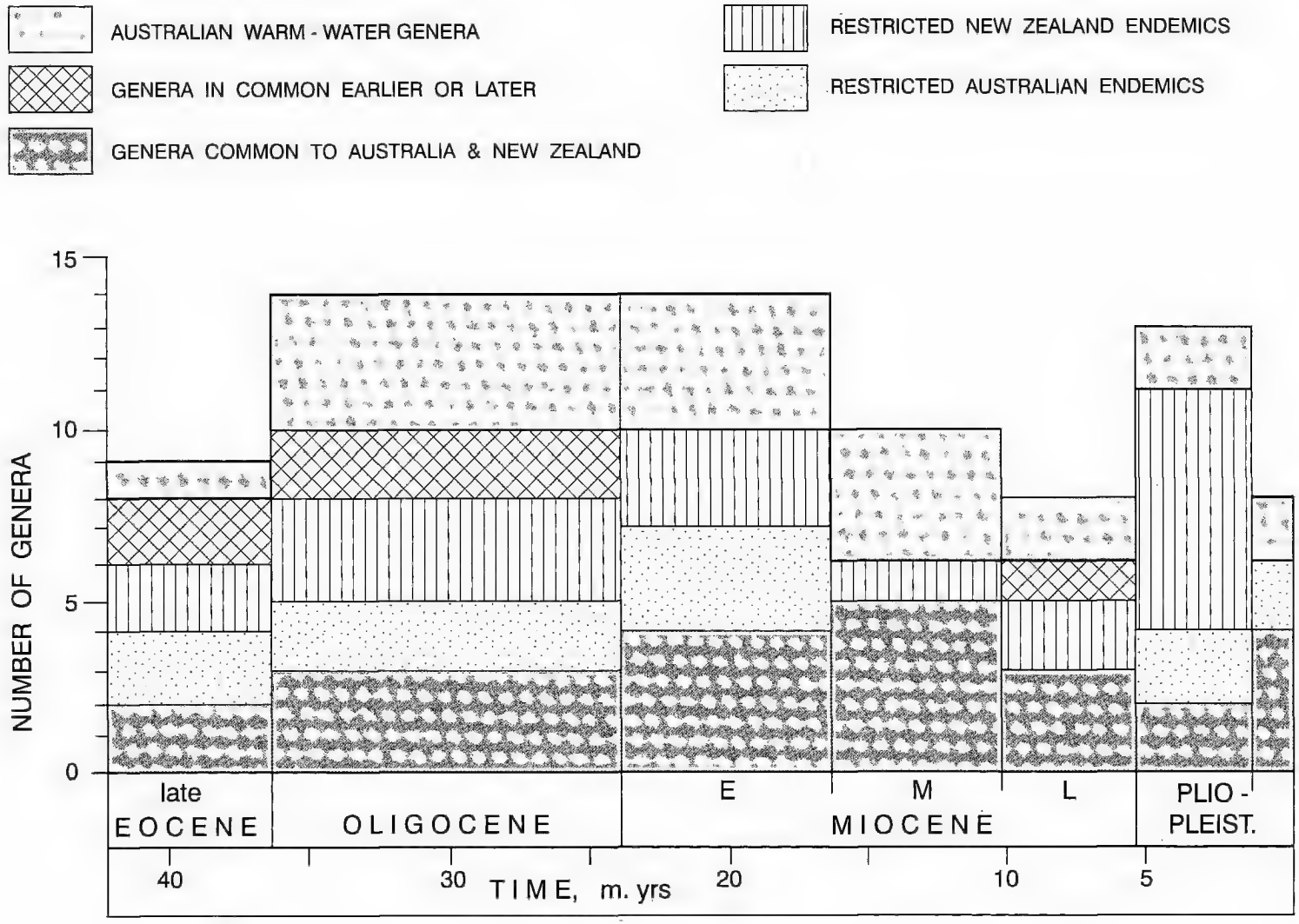
3. *Early genera limited to New Zealand:* Four, or possibly five, genera appeared in New Zealand during early to middle Cenozoic time, but have never reached Australia. Indeed, they all are restricted New Zealand endemic genera (*Athlopecten*, *Duplipecten*, *Lentipecten sensu stricto* (=*Janupecten*) and the Miocene *Lentipecten* homeomorph; the number of *Lentipecten* homeomorphs remains uncertain). All these are now extinct and all had short time ranges in New Zealand, other than the Miocene *Lentipecten* homeomorph.

4. *The New Zealand Pliocene* Mesopeplum *radiation:* At least six genera evolved in New Zealand during Late Miocene–Pliocene time (*Borehamia*, *Kaparachlamys*, *Phialopecten*, *Sectipecten*, *Towaipecten* and gen. nov. cf. *Borehamia*). All are restricted New Zealand endemics, again all becoming extinct late in Pliocene time, and all belong in tribe Palliolini. In other words, this is a radiation from *Mesopeplum* that took place only in New Zealand, none of its members ever having reached Australia. Beu (1995) revised most of the taxa.

5. *Equichlamys bifrons:* The distinctive genus and species *Equichlamys bifrons* is an Australian southern cool-water restricted endemic taxon, which appeared only during Late Pliocene time, still lives in the area, though with a reduced range, and never reached New Zealand. It is concluded below that this species probably is a direct descendent of one or the other of two species we refer to *Equichlamys*, both of which are limited to the Late Oligocene–Early Miocene Monte León Formation (or its lateral equivalent, Chenque Formation) of Argentina.

6. *Plio-Pleistocene arrivals in* both *Australia and New Zealand:* The two genera *Pecten* and *Zygochlamys* are Plio-Pleistocene cool-water arrivals in both regions. *Pecten sensu stricto* is a Pleistocene arrival in the temperate Southern Hemisphere (Fleming 1957). *Pecten* does not occur in South America and as far as we are aware it has no fossil record in South Africa. It appeared in Australia at about the Plio-Pleistocene boundary (*c.* 1.8 Ma) to judge from the sequences in the Perth and Otway basins and on Flinders Island. In contrast, its earliest records in New Zealand, at Mendip Hills Station on the Leader River, North Canterbury, and on the Maraetotara River near Cape Kidnappers, Hawke's Bay (Beu & Maxwell 1990: 335–336) both underlie the Potaka tephra (dated at 1.05 Ma; Shane 1994) by a short interval, and can be little more than 1 my old. *Pecten* also is a conspicuous member of the living fauna in both Australia and New Zealand, occurring all around New Zealand including Stewart Island and the Chatham Islands, and commonly around only the southern, cooler part of Australia (though there are newly recognised occurrences of a tropical species on the Northwest Shelf of Western Australia). The origins of the Australian *Pecten* taxa are discussed below.

Zygochlamys has an extensive fossil record in Argentina since at least Late Eocene time (Beu et al. 1997), and it (or a related genus) first appeared in the New Zealand region (as '*Z*'. *seymouri* Marwick) in the basal Pliocene Momoe-a-toa Shellbed, on northern Chatham Island. The living southern New Zealand and Subantarctic species *Z. delicatula* appeared suddenly and dramatically in the fossil record of the central North Island late in Pliocene time (*c.* 2.5 Ma) and has lived around New Zealand ever since, its range expanding and contracting with the


AUSTRALIAN WARM - WATER GENERA
GENERA IN COMMON EARLIER OR LATER
GENERA COMMON TO AUSTRALIA & NEW ZEALAND
RESTRICTED NEW ZEALAND ENDEMICS
RESTRICTED AUSTRALIAN ENDEMICS
NUMBER OF GENERA
15
10
5
0
late
EOCENE
OLIGOCENE
E
M
L
MIOCENE
PLIO -
PLEIST.
40
30
20
10
5
TIME, m. yrs

temperature oscillations of the Pleistocene. The few records from Australia, listed below, are all from the shelf off either the southeastern-most part of the mainland (Gabo Island to Twofold Bay) or off southeastern-most Tasmania, and all seem likely to date from the Last Glacial Maximum of the terminal Pleistocene. The sharp contrast between the very brief time and geographic range of *Z. delicatula* in Australia and its extensive, complex range in New Zealand reflects the sharp contrast in sea temperatures between Australia and New Zealand during Late Pliocene–Pleistocene time.

Taxonomic faunal turnover

One way of comparing faunal change among pectinids on the two sides of the Tasman Sea is shown in Fig. 2. This is a histogram comparing numbers of genera common to Australia and New Zealand, numbers endemic to one country or the other, and numbers of cosmopolitan warm-water genera occurring in Australia through Cenozoic time. It is compiled in rather broad time bands, because of the difficulty of establishing precise correlation between Australia and New Zealand for much of the Cenozoic.

Although a total of nine, or perhaps even 10, genera common to the two regions is stated at the outset of this section, the most important point arising from Fig. 2 is that there were never more than half this many genera in common at any one time. The number in common rose from two during Eocene time to a maximum of five during the Middle Miocene, presumably reflecting the warmest sea temperatures of the entire period covered by the graph. This was also the only period when only one New Zealand restricted endemic genus and no Australian endemic genera were recorded. At this time, half the total number of recorded genera in the two regions, and all but one of those recorded from New Zealand, were common to Australia and New Zealand. The Australian pectinid fauna consisted only of genera common to Australia and New Zealand and cosmopolitan warm-water genera. Subsequently, the number of genera in common again fell, to return to only two during Pliocene time, and increasing to four during the Pleistocene, with the addition of both *Pecten* and *Zygochlamys* to both faunas.

One category that calls for special comment in this histogram comprises those genera counted as potential or previous genera in common to both regions. *Mesopeplum* and *Austrohinnites* in Late Eocene rocks in New Zealand subsequently became common to both regions, and so were placed in this 'intermediate' category rather than biasing any of the others. The same is true for *Mesopeplum* and *Dichotochlamys* in New Zealand Oligocene rocks, whereas *Austrohinnites* in the Late Miocene column is the opposite case; it lasted on in Australia during Late Miocene time after it extinction in New Zealand. These are the only records included in this category.

A surprising aspect of the histogram is the decrease in the total number of genera in both regions from Oligocene–Early Miocene time up until the Late Miocene. This was caused by decreasing numbers of both Australian and New Zealand endemic genera, as well as by a decrease in Australian occurrences of cosmopolitan warm-water genera. The overall decrease presumably resulted from a combination of the progressive rise and then fall of sea temperatures (Lear et al. 2000), with a sharp decrease in both Australia and New Zealand of the area of outcrop of facies with low deposition rates (limestone, shellbeds and sandstone) after Oligocene–Early Miocene time. Few fossil scallops occur in fine-grained siliciclastic rocks, and facies in which scallops were common were simply less well represented in the Late Miocene stratigraphic column than they were before or later. This effect on the interpretation of Australian molluscan biogeography of the preservation of deep-water versus near-shore facies has been discussed previously by Darragh (1985: 85). Recorded numbers of pectinid genera largely recovered again during Pliocene time, because of the concomitant increase in the record of transgressive shallow-water facies, and because of the radiation in New Zealand of Palliolini related to *Mesopeplum*.

This difference in late Neogene faunal histories appears to reflect the very different late Neogene tectonic and climatic histories of southern Australia and New Zealand. A tectonically stable southern Australia, located somewhat to the north of New Zealand, protrudes into the tropics and enabled cosmopolitan warm-water genera initially to track isotherms southwards, and later to track them again

Fig. 2. Histogram of numbers of pectinid genera in the Australian and New Zealand faunas through Cenozoic time, classified by biogeographic relationships. See text for further explanation.

northwards to retreat around the long Australian coastline as temperatures fell. The extinction of five endemic southern Australian genera (*Abrachlamys*, *Austrohinnites*, *Dichotochlamys*, *Serripecten* and *Victoripecten*), at least two and probably four of them shared with New Zealand, and the retreat to the north (local extinction) of *Annachlamys* and *Amusium* were not followed by new appearances in southern Australia, until the single genus *Equichlamys* appeared late in Pliocene time, to be joined by *Pecten* at about the beginning of the Pleistocene. Both apparently arrived as planktonic larvae in the Antarctic Circum-polar Current. This contrasts strongly with the history of pectinids in isolated, tectonically active New Zealand, where warm-water genera without long-lived planktonic larvae had no accessible refugium, with the consequence that most mid-Cenozoic genera from there became extinct during Middle or Late Miocene time. However, these were replaced during the temperate Late Miocene–Pliocene period of rapid tectonic and sea-level change by rapidly evolving, large, mostly coarsely sculptured descendants of *Mesopeplum*. Continuing decrease in overall sea temperatures with the onset of the Pleistocene mode caused all these Late Miocene–Pliocene endemic genera to become extinct, and enabled the cold-water *Zygochlamys delicatula* to become the only common large scallop until the arrival of *Pecten* about 1 my ago. At present New Zealand lacks all the warm-water pectinid genera that are common in tropical to warm-temperate Australia, as well as all the Australian Late Miocene–Pliocene endemics other than *Mesopeplum*, which it still shares with Australia. *Pecten* and *Talochlamys*—again, both shared with southern Australia—are the only other shallow-water scallop genera living in New Zealand, and *Z. delicatula* is the dominant scallop beyond the shelf edge.

One close parallel in the late Neogene pectinid history of New Zealand and southern Australia is provided by the virtually coeval evolution of large *Mesopeplum* species. The Australian *M. meringae* (Tate) (latest Miocene–Early Pliocene) reached about 100 mm in height, and quite closely resembles the New Zealand *M. (Borehamia) crawfordi* (Hutton) (Early–Middle Pliocene), which reached about 125 mm in height. However, the much smaller, symmetrical auricles and the lack of a byssal notch in *M. crawfordi* contrast strongly with the larger, strongly unequal anterior and posterior auricles and the deep byssal notch retained in adult *M. meringae*, demonstrating that large size evolved independently in *Mesopeplum* in the two regions.

To some extent, the lack of evolution of endemic southern Australian pectinid genera during late Neogene time was made up for by evolution in *Mimachlamys*. Relatively late in its history, during a brief period of rapid change late in Middle Miocene time, the long-static, small species *M. sturtiana* evolved into the much larger *M. asperrima*, which subsequently became the most abundant and wide ranging scallop throughout southern Australia. At some unknown time late in this history, a second lineage of *Mimachlamys* evolved, which gave rise to the other large, distinctive southern Australian species, *M. heterophyseta*, limited to Pleistocene and Recent faunas. Evolution of these large, abundant scallops in some ways mirrored the evolution of endemic temperate genera in New Zealand, but the Australian species remained byssally attached throughout life and did not inhabit the same niche as the New Zealand free-lying taxa.

Faunal turnover in shell shape and sculpture

Considering the scallop fauna of New Zealand and southern Australia as a whole, another marked faunal turnover, paralleling the taxonomic one, can be recognised in shell shape and sculpture. The evolution of swimming in scallops, to avoid predators, has been examined by numerous workers (eg., Yonge 1936; Waller 1969: 16–23; Gould 1971; Thayer 1972; Morton 1980; Joll 1989; Hayami 1991; to list but a few). One of the most enlightening of these accounts for the interpretation of the paleoecology of fossil scallops is the section 'Morphological paradigms for the basic modes of life of scallops' in Johnson (1984: 17–22), who pointed out that, at the present time, the most rapidly swimming, smooth scallops such as *Amusium* and its American homeomorphs that have evolved from *Euvola* (Waller 1991) are limited to tropical and, at most, warm-temperate waters, whereas large, coarsely ribbed, free-lying scallops are largely temperate. The many large, spectacular *Mimachlamys* species in the tropics are not exceptions to this rule, as they apparently all remain byssally attached throughout life, although all byssally attached scallops are able easily to detach themselves and to swim strongly to avoid predators. The one particularly giant species that has sometimes been described as free-lying when adult [*M. townsendi* (G. B. Sowerby III, 1895); Bosch et al. 1995: 230, fig. 1004; to 200 mm high; Gulf of Arabia and northern Arabian Sea] was described by Oliver (in Bosch et al. 1995: 230) as living 'attached to or among rocks, lower shore and below' and so probably even it largely remains

byssally attached when adult. Johnson attributed the distinction between tropical–warm-temperate and cooler-temperate bottom-dwelling scallops to the different groups that exert predation pressure on free-lying scallops. The main temperate predators of bottom-dwelling scallops are extra-orally feeding starfish, and both an increase in shell thickness and an increase in the amplitude of radial folds in the shell (plicae or coarse costae) would increase its resistance to breakage by starfish; most adult temperate bottom-dwelling scallops are probably immune to starfish attack. In the tropics, extra-orally feeding starfish are less diverse than in temperate waters but scallops there face the *added* challenge of predation by durophagous teleost fish. Presuably these can readily crush all scallop shells, so Johnson (1984) attributed the frequently repeated evolution of the thin, light, smooth, weakly inflated shell form with wide gapes at the anterior and posterior ends, enabling rapid swimming by tropical and warm-temperate scallops, to the predatory pressure exerted by fish. Smooth tropical scallops try to swim away from predatory fish with a rapid burst of shell 'clapping', rather than lying still and resisting the opening pressure as they can with temperate starfish. These thin, smooth taxa can swim much better than heavy-shelled, coarsely ribbed ones; Joll (1989) found that the largest specimens of *Amusium balloti*, the most rapid known of modern-day swimmers, can swim at up to 1.6 m/sec (3.1 knots) for up to 23 m in one swimming event, and a total of up to 30 m in one escape reaction, with four swimming events. Maximum swimming speed increases with size in *A. balloti*, so it is not surprising to find that the smaller *A. pleuronectes* swims at up to only 73 cm/sec (Morton 1980).

Some support for the concept that smooth, *Amusium*-like, rapidly swimming scallops also were limited to tropical and warm-temperate waters in the past is seen in their history in Australia and New Zealand. Cenozoic sea temperatures around New Zealand as elsewhere were at their highest during Early to Middle Eocene time (Hornibrook 1978: 436–443, fig. 7.15; Beu & Maxwell 1990: 21; Lear et al. 2000) and at least three homeomorphs of *Amusium* occurred in New Zealand during this time (see the introduction to *Victoripecten* gen. nov., below). During the slightly cooler, but nevertheless warm-temperate to subtropical, period of Late Eocene to Late Miocene time, one or two homeomorphs of *Amusium* were present in New Zealand continuously. Smooth taxa finally became extinct at the end of Late Miocene time, coevally with the further fall in sea temperatures around New Zealand to near-Pleistocene levels, presumably as a result of marked intensification of circulation of the Antarctic Circum-polar Current at that time. Sea temperatures probably remained subtropical to warm-temperate for a longer period in southern Australia, and a similar and probably completely independently evolved history of smooth taxa took place in southern Australia to that in New Zealand. The smooth adamussiine *Victoripecten* is recorded from Late Eocene to Early Miocene rocks, and may well have occurred earlier (pre-Late Eocene molluscan faunas that include pectinids are almost unknown in southern Australia, apart from the one *Delectopecten* species recorded here from the Paleocene Pebble Point Formation). *Amusium* itself also is well represented, with a Late Oligocene–Early Miocene widespread species, an Early Miocene species similar to *A. pleuronectes* limited to the Eucla and Murray basins, a larger species resembling *A. balloti* in Nullarbor Limestone (Eucla Basin), and a few, widespread occurrences of *A. balloti* in Pliocene rocks. The weakly radially sculptured genus *Serripecten* also gave rise to two effectively smooth offshoots that are limited to Australia, an unnamed species during Janjukian (Oligocene) time and *S. semilaevis* (McCoy) during Bairnsdalian–Cheltenhamian time (late Middle–Late Miocene).

During Late Miocene time (a regressive time) a revolution in shell form and sculpture commenced in both Australia and New Zealand. In southern Australia, *Mesopeplum* species and the newly arrived *Equichlamys bifrons*, all with obvious radial plicae, became the dominant bottom-dwelling pectinids by Pliocene time, and remain so now, with the addition of *Pecten* at about the beginning of the Pleistocene. *Amusium* lives now only around the northern, eastern and western coasts, overlapping with *Mesopeplum fenestratum* and *Pecten fumatus* in southern Western Australia and southern Queensland to northern New South Wales. In New Zealand, the radiation of taxa from *Mesopeplum* during the period of moderately elevated but rapidly oscillating Pliocene sea temperatures and rapid tectonic change produced a diverse fauna of bottom-dwelling scallops, all members of which were rather weakly to quite strongly radially sculptured. These all became extinct during the period of increasingly cooler temperatures preceding the Pleistocene, to be replaced in turn by the radially costate bottom-dwelling genera *Pecten* and *Zygochlamys*. Smooth taxa have never again appeared in New Zealand, and *Pecten*, *Mesopeplum* and *Zygochlamys* remain the only free-lying scallops in the modern New Zealand fauna. An exception to the radially sculptured Pliocene taxa in Australia is seen, though, in the appearance of

Amusium balloti in the Late Pliocene of the Murray and St Vincent basins, where it occurred in a single brief marine phase (represented by the coeval Hallett Cove Sandstone and Norwest Bend Formation) alongside the radially sculptured taxon *E. bifrons* (as well as the byssally attached *M. asperrima*). *A. balloti* occurs commonly enough now to support a commercial fishery near Albany, southern Western Australia. Presumably, then, it would have taken only a slight increase in temperature to carry larvae of *A. balloti* further eastwards into southern South Australia in the Leeuwin Current, which at present transports warm surface water southward along the coast of Western Australia and eastward into the Great Australian Bight.

Transport between Australia and New Zealand

For most genera, little of the phylogeny of Australian Cenozoic scallops is yet recorded. Some light on the origins of Australian taxa in common with New Zealand can be deduced by the New Zealand fossil record.

Austrohinnites appears earlier in New Zealand than in southern Australia. The earliest record in New Zealand is a poorly preserved specimen from Kaiata Mudstone (Late Eocene) at Nelson, northern South Island. The early, chlamydoid stage of this specimen is quite well preserved, and there is no doubt about the generic position. The next-youngest record is of the Australian Janjukian *A. corioensis*, but the New Zealand records of Waitakian (earliest Miocene) specimens from at least two widely separated localities are only slightly younger. The New Zealand Late Eocene record is based on a large, apparently typical specimen, which does not offer any light on the origins of the genus. In view of the shallow-water facies inhabited by *Austrohinnites*, and the rather poor record of Eocene shallow facies in both Australia and New Zealand, the genus might well have been present in both regions from earlier Eocene times onwards. What is clear is that it became extinct in New Zealand during or at the end of Waiauan (late Middle Miocene) time, whereas it survived into the Late Miocene in southern Australia.

The above records suggest that Australia and New Zealand have always been on the fringe of the range of *Austrohinnites*, and that it was a stenothermal warm-water genus that extended its range to Australia and New Zealand during the warmest part of the Cenozoic. If so, its main area of occurrence may well have been the Indo-West Pacific province. However, if the living West African shagreen-bearing '*Hinnites*' species prove to be phylogenetically closely related to the Australasian species (see introduction to *Austrohinnites*, below) its main area of occurrence was likely the Atlantic Ocean. If so, *Austrohinnites* might be another of the growing list of molluscan genera transported around the Southern Ocean to Australia and New Zealand in the Antarctic Circumpolar Current (Beu 1976; Beu et al. 1997).

Serripecten is one genus for which the New Zealand record significantly amplifies the Australian one. The relatively coarsely sculptured new species *S. squamocostatus* (recorded only from the Longfordian Stage, Early Miocene) differs in little other than larger size from the four New Zealand Eocene species described and illustrated by Maxwell (1992). There is no older or younger record of Australian species with coarse sculpture of this type. Therefore, it seems likely that this isolated Australian occurrence represents expansion of the geographic range of a New Zealand coarsely sculptured stock to Australia. A still more emphatic need to draw on New Zealand as the provenance of an Australian species is seen in the large, dramatic *S. yahliensis* (Tenison Woods) (= *hutchinsoni* Hutton), which is common to both regions and has no phylogenetically close earlier relatives in Australia, but has a clear record in New Zealand of a smaller ancestor, and of several Eocene lineages, one of which might have given rise to that ancestor.

But where did the other Australian species originate? The huge, relatively finely sculptured *S. carteri*, in Late Miocene rocks of the Gippsland Basin, makes a plausible direct descendent from *S. yahliensis*, but the two earlier species, *S. aldingensis* (Tate) and *S. excultatus* sp. nov., do not closely resemble any other species know to us, either from Australia or New Zealand. The few known specimens of the unnamed Oligocene smooth species seem also to represent a stock that has no other known relative in Australia or New Zealand. On the other hand, it is plausible that the Middle and Late Miocene smooth species *S. semilaevis* (McCoy) evolved directly from *S. yahliensis* by loss of RV sculpture.

Species of *Serripecten* with no obvious close relatives present a common problem in Australasian pectinid phylogeny and biogeography. Some may well represent species groups that lived in southern Australia, in an environment poorly or not represented in the fossil record, for example, beyond the shelf edge, or a glauconite-rich, slow-deposition site. Others might have evolved elsewhere around the Australian continent, eg., in tropical northern Australia, and extended their ranges into southern Australia at favourable times,

whether warmer or cooler than usual. Too many possible explanations are available for one to be any more likely than another in most cases, but at least *Serripecten* does not have the added complication of extending its range to Australia from further afield, as the only other remotely similar pectinid known outside Australia and New Zealand is the North American genus *Batequeus* Squires & Demetrion, 1990 (see introduction to *Serripecten*, below), and its similarity may reflect homeomorphy.

Talochlamys is another genus with a diverse record on both sides of the Tasman Sea, but in this case there appears to be no close relationship between most species groups in the two regions. The living type species, *T. pulleineana* (Tate), shares several phylogenetically important characters with southern Australian fossil species of the *T. badioriva–T. keiloriana* species group, and it seems likely that this represents a rather complex group of lineages that have inhabited southern Australia continuously since their first record late in Eocene time. The species group with wide, prominent costae in New Zealand, including the living *T. dichroa* (Suter), is similar in most characters to the *T. badioriva–T. keiloriana* species group. However, the living New Zealand species *T. dichroa*, at least, differs from Australian ones in having very much more prominent LV preradial microsculpture (Beu 1995: fig. 3f, g). It is quite feasible that these species groups on the two sides of the Tasman Sea are closely related phylogenetically, and that the New Zealand species have retained an original coarse LV preradial microsculpture that has become less prominent in the Australian taxa.

The only other southern Australian fossil genus whose record is amplified by the New Zealand record is *Mesopeplum*. Pre-Miocene records are almost unknown from both regions, reflecting the lack of early Cenozoic shallow-water facies in the stratigraphic record. However, the collection of a single valve from the Late Eocene Kaiata Mudstone at Point Elizabeth Beach, Greymouth, Westland, by Professor Tamio Kotaka (Professor Emeritus, Tohoku University, Sendai, Japan) demonstrates that the genus was present in New Zealand, at least, well before its becoming an abundant fossil. The next earliest record in New Zealand (apart from the poorly understood Oligocene species *M. polymorphoides* Zittel) is of the abundant, long-ranging, coarsely costate species *M. burnetti* (Zittel), recorded from at least earliest Miocene to earliest Pliocene rocks; the Late Eocene record (above) also is of a specimen resembling *M. burnetti*. Although many specimens of *M. burnetti* reach a slightly larger size and have a wider umbonal angle than *M. incertum*, the important point is that this species resembles *M. incertum* much more closely in size, shape and sculpture than does any other Australian species. It seems likely that the New Zealand *M. burnetti* stock expanded its range to Australia at about the end of Early Miocene time, ie., that the main lineages leading to the living species on both sides of the Tasman Sea both have descended from *M. burnetti*. The Australian living species *M. fenestratum* (Hedley) and the New Zealand living species *M. convexum* (Quoy & Gaimard) differ in several quite fundamental characters (see under *M. fenestratum*, below) but likely represent divergent evolution from the same ancestor. Several other species groups occurred in both regions during Miocene and Pliocene times, and it seems unlikely that all the Australian species have descended from *M. burnetti*. In particular, the earliest species recorded from Australia, *M. minimum* sp. nov., is markedly smaller than *M. burnetti* and *M. incertum*, and has the two valves almost equally inflated rather than the RV markedly more inflated than the LV as in *M. burnetti* and *M. incertum*, and so its relationships and origin are unclear. It appears that no other instance of trans-Tasman transport of *Mesopeplum* species has occurred after the Miocene one, and that the subsequent evolution of the Australian species took place in isolation.

The final taxon that clearly has reached southern Australia from New Zealand is *Zygochlamys delicatula*, with a Late Pliocene to Recent record in New Zealand but only a Last Glacial Maximum presence in Australia. Although it is possible that this species reached Australia from South America, either circum-polar dispersal around the Southern Ocean from New Zealand or as a separate, strongly homeomorphic but unrelated species, this possibility seems less likely than direct east to west transport from geographically close New Zealand. All these examples, then, seem to have involved range extensions in one direction only, ie., westward from New Zealand to Australia—and that is the direction opposite to the intuitively expected one, eastwards via the Antarctic Circum-polar Current. One possible range extension from Australia to New Zealand is *Veprichlamys*; the living New Zealand deep-water species *V. kiwaensis* (Powell) quite closely resembles the living Australian type species *V. perillustris* (Iredale), and the genus has a fossil record in Australia but, so far, none in New Zealand.

The one other genus that might have reached New Zealand from Australia is *Mimachlamys*.

Although the earliest New Zealand species of the *Mimachlamys chathamensis* species group is the Late Eocene species illustrated by Maxwell (1992: pl. 3g–i), which is about the same age as the Australian Late Eocene species reported below, this genus was widespread in Europe by Early–Middle Eocene time (Dr T. R. Waller 1999, pers. comm.) and its apparent absence from older rocks in Australia probably merely reflects the lack of preservation of suitable facies. This is suggested by the fact that the only pre-Aldingan Cenozoic fossil pectinid we are aware of in southern Australia is *Delectopecten crassistriatus* sp. nov., from the Paleocene Pebble Point Formation. None of the other distinctive southern Australian Cenozoic pectinids has ever reached New Zealand; the traffic seems to have been mostly one-way.

Transport from further away

Some of the Cenozoic scallops of southern Australia seem to have close fossil relatives elsewhere in the world which occur earlier than they do in Australia or New Zealand, implying dispersal to Australia from further afield as planktonic larvae during Cenozoic time. The clearest example is that of *Equichlamys bifrons* (Lamarck) (discussed under the introduction to *Equichlamys*, below). The only other species we are aware of that could be referred to this genus are the huge Argentinian Early Miocene *E. centralis* (G. B. Sowerby I, 1846) and the coeval, smaller Argentinian species discussed below, under the generic heading. *E. bifrons* arrived abruptly in southern Australia late in Pliocene time, and either of the Argentinian species (but particularly the smaller one) would make a plausible ancestor for *E. bifrons*. This would imply that *Equichlamys* was transported to Australia late in Pliocene time as planktonic larvae via the Antarctic Circum-polar Current. *Notochlamys kendricki* sp. nov. conceivably had a similar history, particularly if the Australian Eocene and Miocene species at present included in *Notochlamys* prove to be only homeomorphs of that genus, but this is not resolvable at present. Again, the relationships of *Austrohinnites* are unclear, and it is possible that it is closely related to the living West African '*Hinnites*' species with shagreen microsculpture (see introduction to *Austrohinnites*, below) and, if so, it may belong in the group of taxa which seems to have been dispersed from southern Africa in the Antarctic Circum-polar Current.

The classic pectinid example of long-distance dispersal late in Neogene time is that of *Pecten*. It is now accepted by molluscan taxonomists (eg., Waller 1991) that Fleming's (1957) premise was correct that the New Zealand and southern Australia *Pecten* species are most closely related to the group of species including *P. benedictus* (Lamarck) and the *P. jacobaeus* (Linné)–*P. maximus* (Linné) species complex. These have a fossil record since Miocene time in southern Europe and around the Mediterranean. It also is clear that *Pecten* arrived in both Australia and New Zealand during early Pleistocene time. As *Pecten* was also a Neogene arrival in Japan, and both living and fossil species occur in the Red Sea area, Fleming (1957) favoured a dispersal route to Australia and New Zealand from the Red Sea and the northern Indian Ocean. However, the relatively recent date of arrival in both Australia and New Zealand suggests that it is equally likely that the temperate species followed the route now known to be common among Southern Ocean gastropods and bivalves (Beu 1976; Beu et al. 1997), from the Atlantic and southern Africa, across the Southern Ocean in the Antarctic Circum-polar Current. The feasibility of this route is shown by the recent recognition of relatives of both *P. jacobaeus* and *P. benedictus* living in South Africa at present (Kilburn & Dijkstra 1995). A further dimension in the history of Australian *Pecten* taxa is introduced by the recent recognition of a living tropical species (observed in WAM collections) on the northwest shelf of Western Australia that previously has been reported mainly from southern Japan. This species apparently lives throughout the western Pacific archipelagos. Skwarko et al. (1994: f9–10) recorded three '*Pecten*' species in the Miocene to Pleistocene tropical fauna of Indonesia. One of these, *P. pyxidatus* (Born 1778) belongs in *Minnivola* Iredale, 1939, but the others appear to be typical species of *Pecten s.s.* Probably then, *Pecten* arrived in Australia by *both* possible routes, the tropical species from the Mediterranean via the Red Sea and Japan and the mid-Pacific, and the temperate species from the southern Atlantic via South Africa.

Evolution in southern Australian Pectinidae

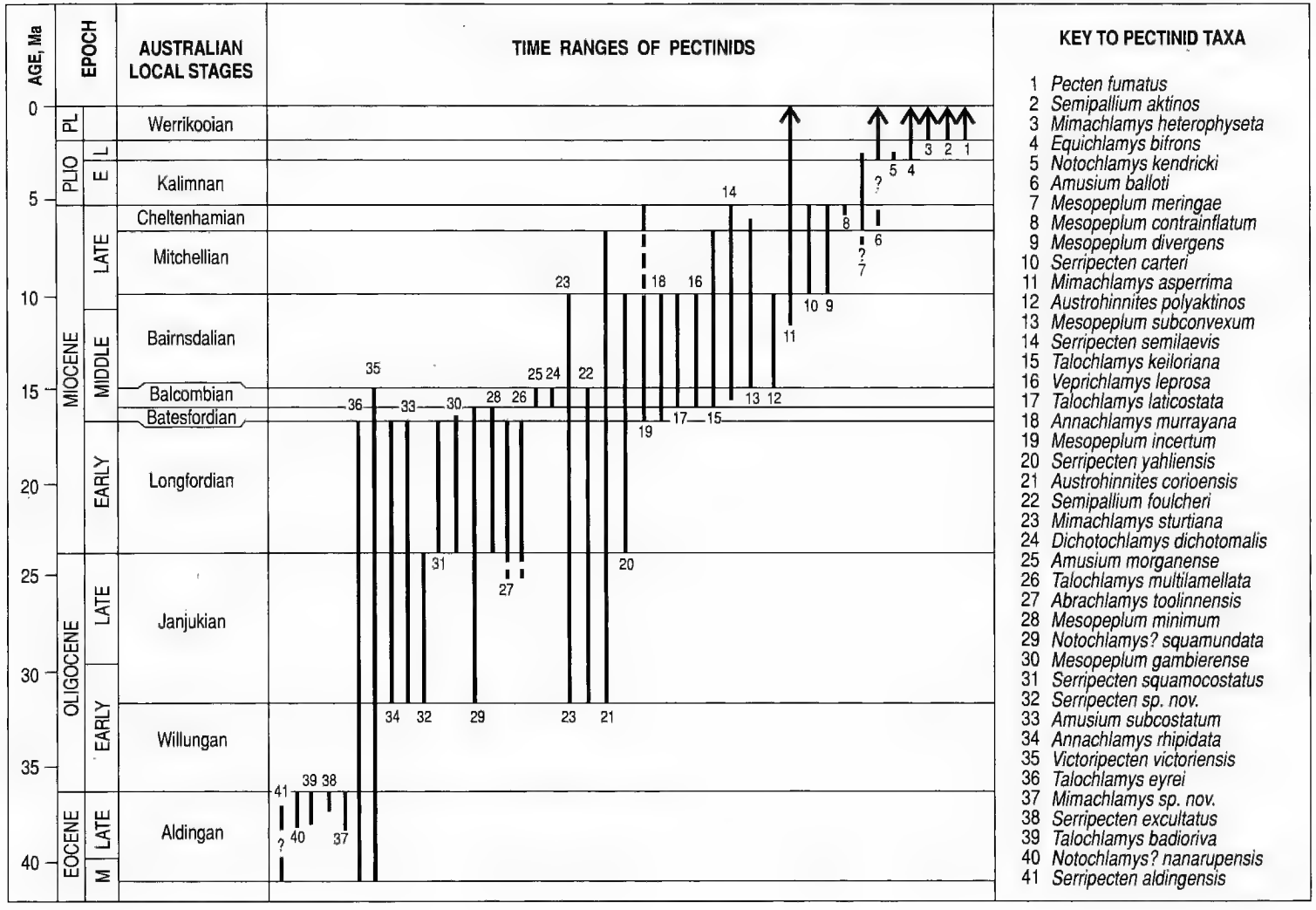
It is disappointing to have to conclude that the fossil record of scallops in southern Australia demonstrates very few speciation events that might help understand evolutionary tempo and mode. In many cases where one species is succeeded abruptly by another, in a manner that provides a useful biostratigraphic event, no record of the presumed speciation event is apparent. In some genera the later species seems unlikely to be descended from

the earlier one, in others no information on the speciation event is manifest in the fossil record even though the two species seem likely to have had an ancestor–descendent relationship, and in still others the question of whether the younger taxon is even closely related phylogenetically to the older is not resolvable from the material presently available. *Austrohinnites corioensis* and *A. polyaktinos* possibly constitute an ancestor–descendent pair, but *A. polyaktinos* appeared cryptically in the Adelaide and St Vincent basins only, with no hint of its origins. The taxa referred to *Notochlamys* remain poorly understood; the two older species may not be correctly referred here, and there is no record of the mode of evolution from the Late Pliocene *N. kendricki* to the Recent *N. hexactes* although, again, this seems likely to be an ancestor–descendent pair. *Semipallium* has no fossil record in southern Australia between the sparse Middle Miocene last records of *S. foulcheri* and the Early Pleistocene appearance of *S. aktinos*, and the genus may well have been absent from the region during this time. *Annachlamys rhipidata* and *A. murrayana* appear not to be closely related phylogenetically. *Mesopeplum minimum* and *M. incertum* are discussed above; they seem unlikely to be an ancestor–descendent pair. However, it does seem likely that *Mesopeplum meringae* was a direct descendent of the only slightly older *M. divergens* sp. nov., in which case a punctuational, allopatric speciation event almost certainly occurred in this lineage but, again, left no record in the rocks. Similarly, *M. subconvexum* possibly evolved from *M. incertum* through an abrupt speciation event, but it is not at all clear whether these species are as closely related as they might appear. The discovery of a specimen in the Late Miocene of Gippsland, intermediate in some characters between *M. incertum* and *M. fenestratum* (see under *M. fenestratum*, below), indicates that *M. subconvexum* was not closely related to *M. fenestratum*. The fossil record of *Mesopeplum* is vitiated by the limitation of some species to discrete lithologies, allowing several apparently unrelated taxa to occur coevally. It also seem likely that the fossil record of former species is very incomplete in *Mesopeplum*. Finally, the three southern Australian *Amusium* species are unrelated, in a close phylogenetic sense.

One genus where a clear evolutionary series appears to be preserved is *Talochlamys*. The Late Eocene *T. badioriva* has many characters in common with the Middle and Late Miocene *T. keiloriana*, and appears likely to have been its immediate ancestor. In this case, though, the fossil record is neither continuous nor unambiguous enough to throw any light on the mode of evolution; it is as likely to have been gradual and anagenetic as it is to have resulted from an abrupt speciation event. Similarly, *T. keiloriana* may well have been the direct ancestor of the living type species, *T. pulleineana* (Tate), but there is no record of this species group between the Late Miocene apparent extinction of *T. keiloriana* and the Recent occurrence of *T. pulleineana*.

An important aspect of pectinid evolution that *does* have some light shed on it by southern Australian scallops, though, is the evolution of the various types of LV preradial microsculpture. As is commented on in more detail under the relevant genera, in *Semipallium*, *Veprichlamys* and *Mimachlamys*, earlier species all have markedly coarser LV preradial microsculpture than the later species—the living ones, in most cases. In all these genera, the earlier species demonstrate that the weak sculpture of late Neogene and living species, which is quite similar in a number of apparently unrelated genera, has evolved from a range of types of coarser sculpture. Most significantly, the LV preradial microsculpture of *Mimachlamys asperrima*, consisting of shallow, evenly concave pits in an otherwise smooth surface, evolved from a markedly coarser sculpture of intersecting commarginal and antimarginal ridges. This sculpture is strongly developed on Early Miocene specimens and more weakly developed on Middle Miocene specimens all referred to *M. sturtiana*. In this lineage, and also in *Semipallium foulcheri*, the LV preradial microsculpture passed through an evolutionary series of progressive weakening, as if the coarser early sculpture gradually sank into the background. In the case of *Mimachlamys*, this suggests the possibility that the almost smooth, weakly pitted LV preradial microsculpture might have evolved more than once, so that the tropical species referred to *Mimachlamys* elsewhere in the world might be homeomorphs of the southern Australian *Mimachlamys sensu stricto*. This possibility receives some support from the virtual absence of internal rib carinae in most southern Australian specimens of *Mimachlamys*, and their contrasting prominence in the tropical species. However, the presence of carinae in some thick-shelled specimens of the southern Australian Pleistocene to Recent species *M. heterophyseta* sp. nov. indicates that the presence or absence of carinae depends on shell thickness and costal prominence, and does not support the existence of more than one phylogenetic group among the species referred to *Mimachlamys*.

One final point about the evolution of southern Australian scallops that is valuable for under-


AGE, Ma
EPOCH
AUSTRALIAN LOCAL STAGES
TIME RANGES OF PECTINIDS
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PL
E
L
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OLIGOCENE
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Werrikooian
Kalimnan
Cheltenhamian
Mitchellian
Bairnsdalian
Balcombian
Batesfordian
Longfordian
Janjukian
Willungan
Aldingan
0
5
10
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20
25
30
35
40
KEY TO PECTINID TAXA
1 Pecten fumatus
2 Semipallium aktinos
3 Mimachlamys heterophyseta
4 Equichlamys bifrons
5 Notochlamys kendricki
6 Amusium balloti
7 Mesopeplum meringae
8 Mesopeplum contrainflatum
9 Mesopeplum divergens
10 Serripecten carteri
11 Mimachlamys asperrima
12 Austrohinnites polyaktinos
13 Mesopeplum subconvexum
14 Serripecten semilaevis
15 Talochlamys keiloriana
16 Veprichlamys leprosa
17 Talochlamys laticostata
18 Annachlamys murrayana
19 Mesopeplum incertum
20 Serripecten yahliensis
21 Austrohinnites corioensis
22 Semipallium foulcheri
23 Mimachlamys sturtiana
24 Dichotochlamys dichotomalis
25 Amusium morganense
26 Talochlamys multilamellata
27 Abrachlamys toolinnensis
28 Mesopeplum minimum
29 Notochlamys? squamundata
30 Mesopeplum gambierense
31 Serripecten squamocostatus
32 Serripecten sp. nov.
33 Amusium subcostatum
34 Annachlamys rhipidata
35 Victoripecten victoriensis
36 Talochlamys eyrei
37 Mimachlamys sp. nov.
38 Serripecten excultatus
39 Talochlamys badioriva
40 Notochlamys? nanarupensis
41 Serripecten aldingensis

standing modes of speciation is the evolution of *Mimachlamys asperrima* from *M. sturtiana* (described in more detail below, under *M. asperrima*). This appears to be an example of a relatively brief, but still geologically rather slow, anagenetic side-step in an otherwise static lineage. The static history of *M. sturtiana*, over about 20 my, was followed by a period of relatively slow change, over perhaps 1.5–2 my, followed in turn by the static history of *M. asperrima*, which continues still, *c.* 10 my after its first appearance. This is a decidedly unusual mode of speciation, and it is unfortunate that the southern Australian fossil record does not, as yet, reveal more about the modes of speciation of the diverse scallops represented therein.

BIOSTRATIGRAPHY

Figures 3 and 4 are diagrams of the time ranges of the Australian fossil pectinids revised in this work, plotted against Australian stages in the AGSO Australian Cenozoic time scale (Chaproniere et al. 1996) and against the ages of the southern Australian rock units from which we have identified pectinids. The stratigraphy and ages of rock units we refer to here, in the many discrete and widely dispersed sedimentary basins in southern Australia, are shown in Fig. 5, and the younger rocks are shown in more detail in Fig. 6. Li et al. (1999) recently have confirmed by foraminiferal biostratigraphy the ages we have accepted for units in the Torquay section, Victoria (type section of Janjukian Stage, and overlying units). Li & McGowran (1999) also recently have confirmed ages we have adopted (following Lindsay & Giles 1973) for the Murray River limestones. Before considering some of the biostratigraphic results of this work, it is important to consider reasons for the ages adopted for some other rock units in southern Australia.

Relative ages of southern Australian Plio-Pleistocene faunas

In the absence of foraminiferal or other microfossil biostratigraphy to place southern Australian fossiliferous Plio-Pleistocene units in an independently dated sequence, superposition in this sequence must be based on molluscan faunas (Darragh 1985), and the little foraminiferal biostratigraphy where known (Carter 1964; Wilkins 1963; Abele et al. 1976). Correlation with the more continuous, much thicker, and better-dated sequence in New Zealand also helps in some cases.

Age of the Hartungia *lineage in New Zealand*

One useful means of correlating between Australian and New Zealand Pliocene rocks is the latest Miocene to earliest Pleistocene genus *Hartungia* Bronn, a world-wide pelagic gastropod of the Family Janthinidae (Fleming 1953; Beu & Maxwell 1990: 292, pl. 37a, b). The apparently world-wide, geologically instantaneous speciation event marking the evolution of *H. typica* Bronn into *H. chavani* Ludbrook (1978: 119, pl. 12, figs 1–14) occurs in New Zealand at the Waipipian–Mangapanian stage boundary in two well-dated sections (Beu, unpub.). This stage boundary currently is dated at 3.2 Ma, about mid-Piacenzian, early in the Late Pliocene. The earliest record of *H. typica* in New Zealand is in late Kapitean rocks (latest Miocene, Messinian) in the Te Araroa section, near East Cape. The youngest records of *H. chavani* are:

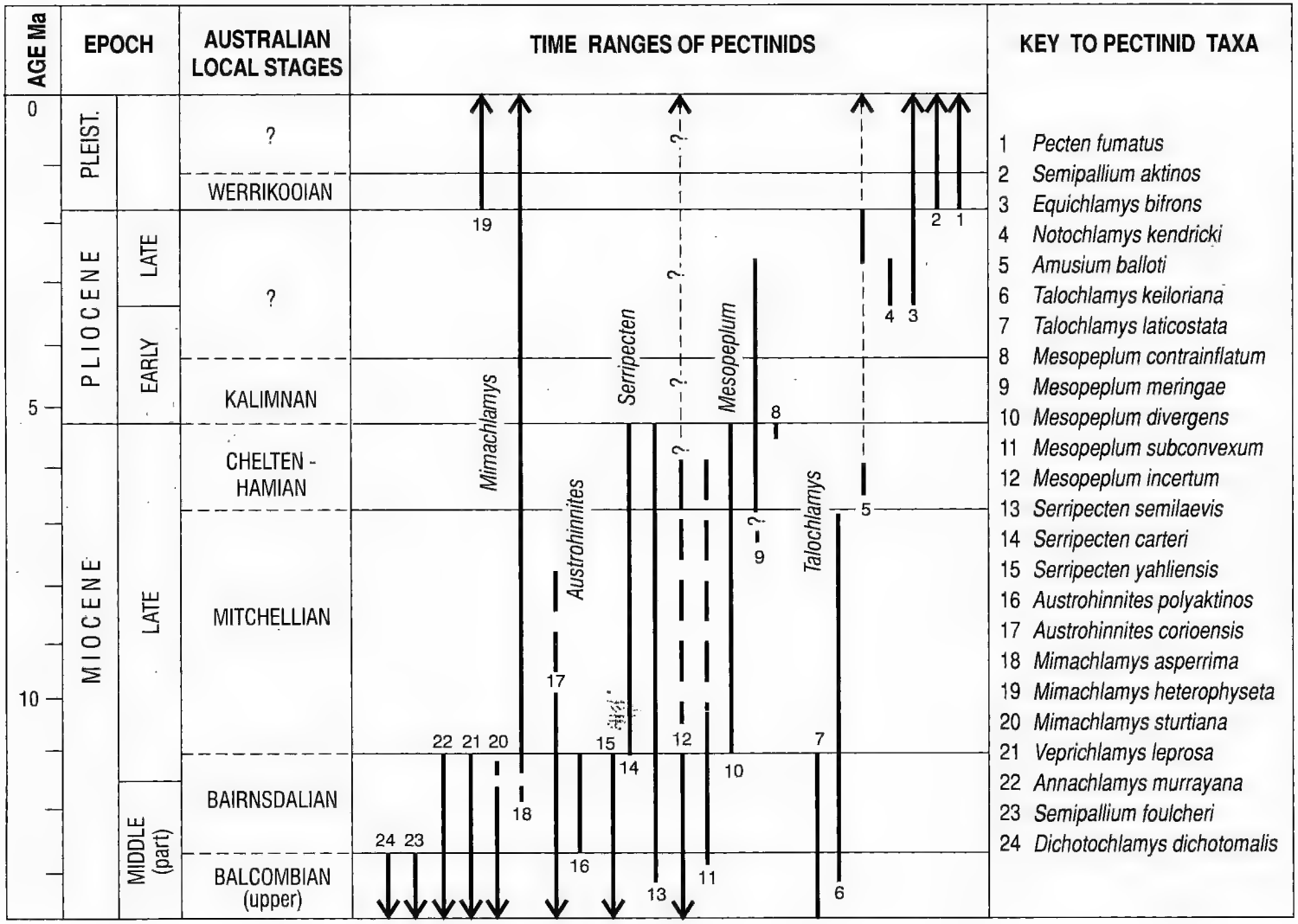
1. *In the East Coast Basin:* in Darkys Spur Formation, near the Devils Elbow section, *c.* 30 km north of Napier on the Napier–Wairoa highway (Haywick et al. 1991). This horizon is slightly below the correlated position of the Pliocene–Pleistocene stratotype boundary as defined at Vrica, Calabria (Aguirre & Pasini 1985).

2. *In Wanganui Basin:* a short distance below Vinegar Hill Tephra in a cutting on Brunswick Road, Kai Iwi Valley, *c.* 10 km west of Wanganui; this tephra is dated at 1.75 Ma (Naish et al. 1998; Pillans et al. 1994) and the *Hartungia chavani* occurrence is just above the correlated position of the Pliocene–Pleistocene boundary at Vrica.

We therefore conclude that *Hartungia chavani* became extinct at or very slightly after the Plio-Pleistocene boundary. The correlations we adopt for the *Hartungia* species are:

1. *Hartungia typica* Bronn (= *Heligmope dennanti* Tate): latest Miocene to early Late Pliocene (*c.* 5.5 to 3.0 Ma);

Fig. 3. Time ranges of the Australian Cenozoic Pectinidae revised in this report, plotted against the AGSO Cenozoic time scale (Chaproniere et al. 1996). The upper part of the diagram is shown in more detail in Fig. 4. Ages of rock units used for correlation of time ranges are shown in Figs 5 and 6.


AGE Ma
EPOCH
AUSTRALIAN LOCAL STAGES
TIME RANGES OF PECTINIDS
KEY TO PECTINID TAXA
0
5
10
PLEIST.
PLIOCENE
MIOCENE
LATE
EARLY
LATE
MIDDLE (part)
?
WERRIKOOIAN
?
KALIMNAN
CHELTEN - HAMIAN
MITCHELLIAN
BAIRNSDALIAN
BALCOMBIAN (upper)
Mimachlamys
Austrohinnites
Serripecten
Mesopeplum
Talochlamys
1 Pecten fumatus
2 Semipallium aktinos
3 Equichlamys bifrons
4 Notochlamys kendricki
5 Amusium balloti
6 Talochlamys keiloriana
7 Talochlamys laticostata
8 Mesopeplum contrainflatum
9 Mesopeplum meringae
10 Mesopeplum divergens
11 Mesopeplum subconvexum
12 Mesopeplum incertum
13 Serripecten semilaevis
14 Serripecten carteri
15 Serripecten yahliensis
16 Austrohinnites polyaktinos
17 Austrohinnites corioensis
18 Mimachlamys asperrima
19 Mimachlamys heterophyseta
20 Mimachlamys sturtiana
21 Veprichlamys leprosa
22 Annachlamys murrayana
23 Semipallium foulcheri
24 Dichotochlamys dichotomalis

2. *Hartungia chavani* Ludbrook: early Late Pliocene to about the Plio-Pleistocene boundary (*c.* 3.0–1.8 Ma).

Pliocene correlations in southern Australia

The essential question to be answered about southern Australian Pliocene correlations is the relative ages of Ascot Formation ('older' and 'younger') in the Perth Basin; Roe Calcarenite in the Eucla Basin; Dry Creek Sands and Hallett Cove Sandstone in the St Vincent Basin; Norwest Bend Formation and Bookpurnong Formation in the Murray Basin; Whalers Bluff Formation in the Otway Basin; and Memana Formation and Cameron Inlet Formation in the Bass Basin, in relation to Jemmys Point Formation in the Gippsland Basin. Some of these questions have been answered, at least in part, by Darragh (1985), who showed that Cameron Inlet Formation is a little younger than Jemmys Point Formation, and Memana Formation is younger still. Kendrick et al. (1991) located the Roe Calcarenite and the older part of the Ascot Formation within the late Pliocene and the younger Ascot Formation was correlated with the Werrikooian Stage of southeast Australia.

Important points for correlation about the occurrences of *Hartungia* taxa in southern Australia are:

1. *H. chavani* occurs in Roe Calcarenite (the type formation for the species), in Hallett Cove Sandstone, and in 'older' Ascot Formation beneath Perth (specimens examined in WAM with G. W. Kendrick).

2. *H. typica* is recorded only from Kalimnan rocks, both in Grange Burn Formation in the Otway Basin and in Jemmys Point Formation in the Gippsland Basin.

3. Werrikoo Limestone, Glenelg River, contains *Zenatiopsis ultima* (Darragh, in Singleton et al. 1976) but *Hartungia* has not been found in this formation; in this section, *Pecten fumatus* appears in the beds in the Whalers Bluff Formation overlying Werrikoo Limestone.

We show below that a new species of *Mimachlamys*, *M. heterophyseta*, occurs in both Memana Formation and the 'younger' Ascot Formation of the Perth Basin, strengthening evidence for the correlation of these two formations already provided by the occurrence in both of them of the youngest *Zenatiopsis* species (Darragh & Kendrick 1971). The 'younger' Ascot Formation does not contain *Hartungia*, whereas the 'older' Ascot Formation contains *H. chavani* in abundance, providing evidence that the Plio-Pleistocene boundary lies between these two diachronous and disconformable units. The 'younger' Ascot Formation also contains *Pecten fumatus*, which as is noted below, seems to be a Pleistocene arrival in both Australia and New Zealand; *Pecten* is not recorded from the 'older' Ascot Formation, nor from the Roe Calcarenite. These occurrences and correlations therefore suggest that Memana Formation of Flinders Island is Early Pleistocene, Cameron Inlet Formation lies somewhere within the Late Pliocene, and Jemmys Point Formation is Cheltenhamian (latest Miocene) at the base and Kalimnan (Early Pliocene) above that, but entirely predates Cameron Inlet Formation. The few records of *Pecten* from Memana Formation are subject to confirmation because of the possibility of contamination from overlying Holocene beds, but as several *Pecten* records are from localities to the south of known Holocene outcrops, they are accepted tentatively as authentic.

Ludbrook (1978: 29–30) suggested an Early Pleistocene age for Roe Calcarenite in the Eucla Basin, based on the Lyellian percentage of its fauna found in younger rocks and in the living fauna, compared with that found in older rocks. The presence of abundant, exquisitely preserved *Hartungia chavani*, though, indicates (to judge from the New Zealand succession) a Late Pliocene age. But what is its age relative to the Perth, St Vincent and Murray Basin successions? The Roe Calcarenite pectinid fauna includes abundant *Equichlamys bifrons*, evidently a late arrival in Australia, found elsewhere in Hallett Cove Sandstone, in Norwest Bend Formation, in Memana Formation, in Werrikoo Limestone, and in both 'older' and 'younger' Ascot Formation, but neither in the Kalimnan Jemmys Point and Grange Burn formations nor in Cameron Inlet Formation. The Roe Calcarenite pectinids also include a new endemic *Notochlamys* species, *N. kendricki*, distinct from the living *N. hexactes*, suggesting that the Roe Calcarenite fauna might be older than all other Late Pliocene faunas in the Perth, St Vincent and Murray basins. The Roe Calcarenite fauna also has a warm-water aspect, containing such taxa as *Chicoreus*, *Veremolpa* and *Cucullaea*, which are not present in Late Pliocene rocks of the St Vincent

Fig. 4. Time ranges of Australian late Neogene fossil pectinids, ie., enlargement of the upper part of Fig. 3.

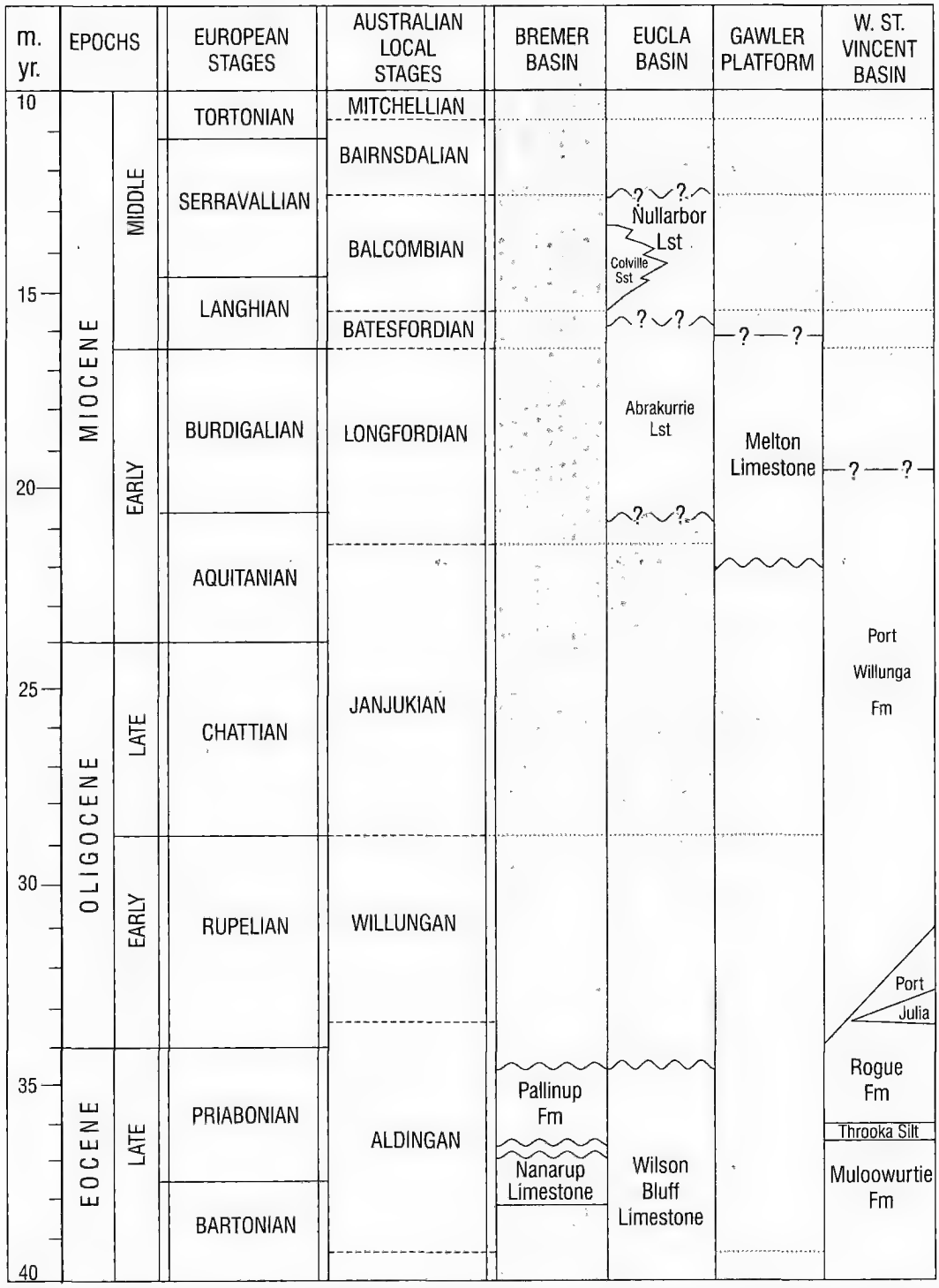
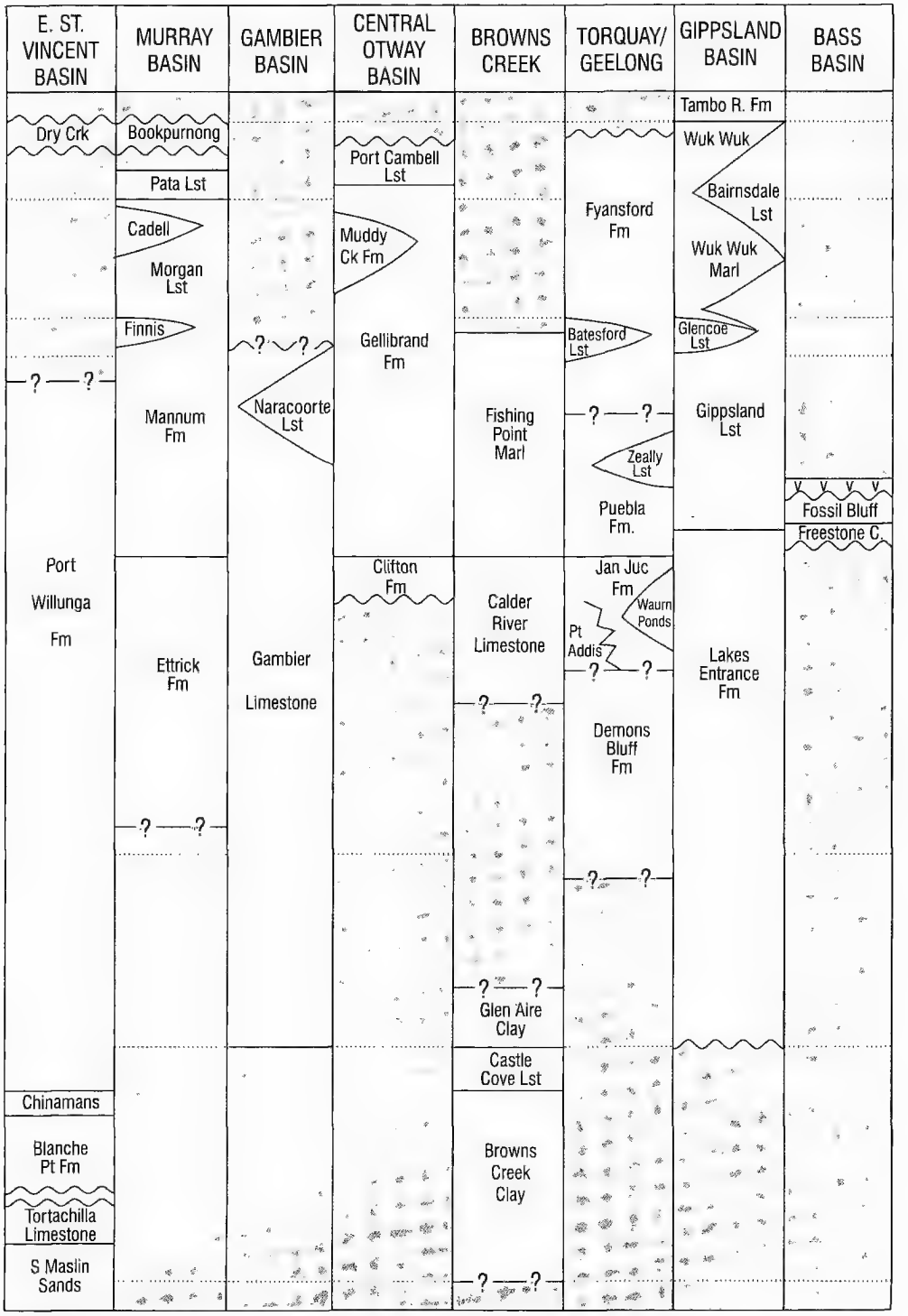
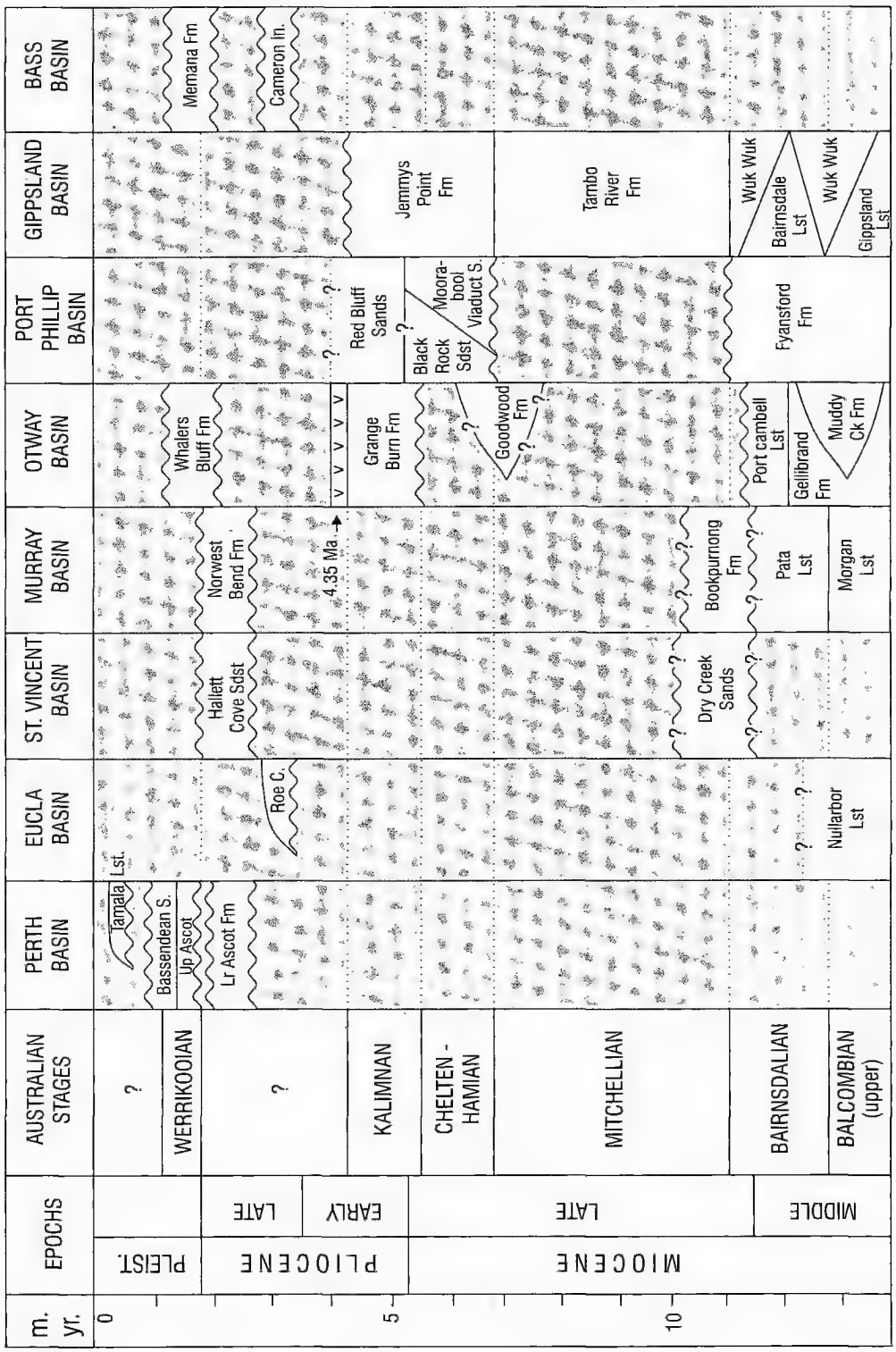


Fig. 5. Ages and stratigraphic relationships of the Cenozoic rock units of southern Australia referred to in


E. ST. VINCENT BASIN
MURRAY BASIN
GAMBIER BASIN
CENTRAL OTWAY BASIN
BROWNS CREEK
TORQUAY/ GEELONG
GIPPSLAND BASIN
BASS BASIN
Dry Crk
Bookpurnong
Pata Lst
Cadell
Morgan Lst
Finnis
Mannum Fm
Port Willunga Fm
Ettrick Fm
Gambier Limestone
Naracoorte Lst
Port Cambell Lst
Muddy Ck Fm
Gellibrand Fm
Clifton Fm
Fishing Point Marl
Calder River Limestone
Glen Aire Clay
Castle Cove Lst
Browns Creek Clay
Fyansford Fm
Batesford Lst
Zeally Lst
Puebla Fm.
Jan Juc Fm
Waurn Ponds
Pt Addis
Demons Bluff Fm
Tambo R. Fm
Wuk Wuk
Bairnsdale Lst
Wuk Wuk Marl
Glencoe Lst
Gippsland Lst
Lakes Entrance Fm
Fossil Bluff
Freestone C.
Chinamans
Blanche Pt Fm
Tortachilla Limestone
S Maslin Sands

this report.


m. yr.
EPOCHS
AUSTRALIAN STAGES
PERTH BASIN
EUCLA BASIN
ST. VINCENT BASIN
MURRAY BASIN
OTWAY BASIN
PORT PHILLIP BASIN
GIPPSLAND BASIN
BASS BASIN
PLEIST.
PLIOCENE
MIOCENE
LATE
EARLY
MIDDLE
LATE
?
WERRIKOOIAN
KALIMNAN
CHELTEN - HAMIAN
MITCHELLIAN
BAIRNSDALIAN
BALCOMBIAN (upper)
0
5
10
Tamala Lst.
Bassendean S.
Up Ascot
Lr Ascot Fm
Roe C.
Nullarbor Lst
Hallett Cove Sdst
Dry Creek Sands
Norwest Bend Fm
4.35 Ma
Bookpurnong Fm
Pata Lst
Morgan Lst
Whalers Bluff Fm
Grange Burn Fm
Goodwood Fm
Port cambell Lst
Gellibrand Fm
Muddy Ck Fm
Red Bluff Sands
Black Rock Sdst
Moora-bool Viaduct S.
Fyansford Fm
Jemmys Point Fm
Tambo River Fm
Wuk Wuk
Bairnsdale Lst
Gippsland Lst
Memana Fm
Cameron In.

or Murray basins. We therefore conclude that Roe Calcarenite is older than all other Late Pliocene faunas in the Perth, St Vincent and Murray basins, although still younger than Victorian Kalimnan rocks.

It is therefore concluded that the 'older' Ascot Formation, Hallett Cove Sandstone, Norwest Bend Formation, Dry Creek Sands (upper part only; see below), and possibly Werrikoo Limestone approximately are coeval, and all are younger within the Late Pliocene than Roe Calcarenite. The 'younger' Ascot Formation we agree with Kendrick et al. (1991) to be Early Pleistocene, coeval with Memana Formation, as it: (a) contains *Pecten fumatus*, *Mimachlamys heterophyseta* and *Zenatiopsis ultima*; and (b) seems to be above the range of *Hartungia chavani*.

Abrakurrie Limestone

Abrakurrie Limestone overlies Wilson Bluff Limestone, including 'Toolinna limestone facies' (Late Eocene) and underlies Nullarbor Limestone (Balcombian, Middle Miocene) in the Eucla Basin, southeastern Western Australia. An age of Early to early Middle Miocene (Longfordian to Batesfordian) has been adopted for Abrakurrie Limestone previously (Longfordian; Lowry 1970: 84) but Li et al. (1996) and McGowran et al. (1997) recently assigned it an Oligocene-basal Miocene age (Janjukian–'upper Janjukian').

Pectinidae present in Abrakurrie Limestone are *Abrachlamys toolinnensis* gen. et sp. nov. (restricted to the formation), *Notochlamys squamundata* sp. nov., a few fragmentary specimens (Aldingan–Longfordian elsewhere), *Talochlamys multilamellata* sp. nov. (restricted to the formation), *Victoripecten victoriensis* (Crespin) (Aldingan–Batesfordian and, rarely, Balcombian elsewhere; but the Abrakurrie Limestone specimens resemble Janjukian and younger specimens from elsewhere), and *Annachlamys* sp. nov.?, closely resembling the specimen from Poivre Formation (Middle Miocene) on Barrow Island, Western Australia, illustrated by McNamara & Kendrick (1994: fig. 8B). Obviously, almost all these pectinids are either long-ranging, or are restricted to this formation. The *Annachlamys* is the one pectinid suggesting a restricted age, and it seems to indicate an age younger than that usually assigned, rather than older. Possibly the pectinids, or at least the *Annachlamys* specimen, were collected from high in the formation; this might also be a distinct *Annachlamys* species from that in Poivre Formation. Certainly, this specimen does not seem to indicate an age as old as Janjukian (ie., it is distinct from the Janjukian–Longfordian *A. rhipidata* sp. nov.), and we have retained a Longfordian age for Abrakurrie Limestone. Collection of stratigraphically controlled material may well enable pectinid zonation of such units deposited during a significant time period, but zonation is not possible for Abrakurrie Limestone at present. Ludbrook (in Lowry 1970: fig. 21) illustrated several other pectinids from Wilson Bluff Limestone and Abrakurrie Limestone, but all appear to be misidentified, and they do not help the age assignment.

Recognition of Australian Cenozoic stages by their pectinids

The accompanying range charts of pectinid taxa (Figs 3, 4) demonstrate that, in suitable facies—mostly limestone and relatively shallow-water siliciclastic lithologies, particularly with low sedimentation rates—pectinids are helpful for the recognition of Australian local Cenozoic stages. The Paleocene Pebble Point fauna includes only the one pectinid, *Delectopecten crassistriatus* sp. nov., and no other pectinids are recorded from other early Cenozoic stages before the Aldingan. Pectinid taxa useful for recognising Australian stages are listed below, commencing with the Aldingan Stage.

1. *Aldingan:* The Aldingan Stage has one of the more distinctive pectinid faunas of southern Australian stages, and it is recognisable more widely than most of the others: from the Johanna coast west of Cape Otway, Victoria, westwards to southern Western Australia.

Restricted taxa: *Serripecten aldingensis* (widespread), *Talochlamys badioriva* (widespread), *Serripecten excultatus* (limited to Otway Basin), *Mimachlamys* sp. nov. (recorded only from St Vincent Basin).

First appearance of taxa: *Talochlamys eyrei*, *Victoripecten victoriensis*.

2. *Willungan:* Very few pectinids recorded; *Talochlamys eyrei* and *Victoripecten victoriensis* continue.

First appearance of taxa: *Semipallium foulcheri* (rare).

Fig. 6. Late Neogene (late Middle Miocene–Pleistocene) rock units of southern Australia referred to in this work, showing their ages and stratigraphic relationships.

3. *Janjukian: Talochlamys eyrei* and *Victoripecten victoriensis* continue.

Last appearance of taxa: none.

Restricted taxa: *Serripecten* sp. nov. (smooth).

First appearance of taxa: *Notochlamys squamundata*, *Annachlamys rhipidata*, *Amusium subcostatum*, *Mimachlamys sturtiana*, *Semipallium foulcheri* (common), *Austrohinnites corioensis*.

4. *Longfordian: Victoripecten victoriensis*, *Mimachlamys sturtiana*, *Semipallium foulcheri* and *Austrohinnites corioensis* all continue.

Last appearance of taxa: *Talochlamys eyrei*, *Annachlamys rhipidata* (common), *Amusium subcostatum*, *Notochlamys squamundata*.

Restricted taxa: *Abrachlamys toolinnensis*, *Talochlamys multilamellata* (both recorded only from Abrakurrie Limestone, Eucla Basin); *Serripecten squamocostatus*.

First appearance of taxa: *Mesopeplum minimum*, *M. gambierense*, *Serripecten yahliensis*.

5. *Batesfordian: Victoripecten victoriensis*, *Mimachlamys sturtiana*, *Semipallium foulcheri*, *Austrohinnites corioensis* and *Serripecten yahliensis* all continue.

Last appearance of taxa: *Mesopeplum gambierense*, *M. minimum*.

Restricted taxa: none.

First appearance of taxa: *Mesopeplum incertum*, *Annachlamys murrayana*.

6. *Balcombian: Mimachlamys sturtiana*, *Semipallium foulcheri*, *Austrohinnites corioensis*, *Serripecten yahliensis*, *Mesopeplum incertum* and *Annachlamys murrayana* all continue.

Last appearance of taxa: *Victoripecten victoriensis* (few records), *Semipallium foulcheri* (few records).

Restricted taxa: *Amusium morganense* (Eucla and Murray basins only), *Dichotochlamys dichotomalis* (largely limited to Port Phillip Basin).

First appearance of taxa: *Talochlamys laticostata* (Murray Basin only), *T. keiloriana*, *Veprichlamys leprosa* (limited to Port Phillip Basin), *Serripecten semilaevis* (few records, Muddy Creek only).

7. *Bairnsdalian: Austrohinnites corioensis*, *Talochlamys keiloriana* and *Serripecten semilaevis* continue; *S. semilaevis* and *Mesopeplum subconvexum* are particularly abundant and characteristic of the stage.

Last appearance of taxa: *Mimachlamys sturtiana*, *Serripecten yahliensis*, *Mesopeplum incertum*, *Annachlamys murrayana*, *Talochlamys laticostata*, *Veprichlamys leprosa*.

Restricted taxa: *Austrohinnites polyaktinos* (St Vincent and Murray basins only).

First appearance of taxa: *Mesopeplum subconvexum*, *Mimachlamys asperrima*.

8. *Mitchellian: Serripecten semilaevis* and *Mimachlamys asperrima* continue.

Last appearance of taxa: *Austrohinnites corioensis*, *Talochlamys keiloriana* (few records, limited to Gippsland Basin).

Restricted taxa: none.

First appearance of taxa: *Serripecten carteri* (Port Phillip and Gippsland basins only), *Mesopeplum divergens* (Port Phillip and Gippsland basins only), *M. meringae* (Gippsland and Bass basins only).

9. *Cheltenhamian: Mimachlamys asperrima* and *Mesopeplum meringae* continue.

Last appearance of taxa: *Serripecten semilaevis*, *S. carteri*, *Mesopeplum subconvexum*, *M. divergens*.

Restricted taxa: *Mesopeplum contrainflatum* (one locality only in Gippsland Basin).

First appearance of taxa: *Amusium balloti* (one record, Gippsland Basin).

10. *Kalimnan: Mimachlamys asperrima* and *Mesopeplum meringae* continue.

NO last appearances, restricted taxa, or first appearances.

11. *Late Pliocene, post-Kalimnan: Mimachlamys asperrima* and *Amusium balloti* continue.

Last appearance of taxa: *Mesopeplum meringae* (limited to Bass Basin).

Restricted taxa: *Notochlamys kendricki* (limited to Eucla Basin).

First appearance of taxa: *Equichlamys bifrons*.

12. *Pleistocene: Mimachlamys asperrima*, *Amusium balloti* and *Equichlamys bifrons* continue.

Last appearance of taxa: none.

Restricted taxa: *Zygochlamys delicatula*, but only on the southeast continental shelf.

First appearance of taxa: *Mimachlamys heterophyseta*, *Semipallium aktinos*, *Pecten fumatus*.

Some results from the biostratigraphy

1. *Age of Dry Creek Sands:* Dry Creek Sands, wholly subsurface, St Vincent Basin, contains the following scallops:

(a) *Austrohinnites polyaktinos* (Ludbrook); this is the '*Hinnites*' reported by Ludbrook (1973: pl. 27, fig. 78) in Bookpurnong Formation, Murray Basin (Bairnsdalian). It is abundant in our collections from Bookpurnong Formation.

(b) *Mesopeplum subconvexum* (Tate); this is the species recorded by Ludbrook (1955) as *M. incertum*. Comparison with specimens from Bookpurnong Formation, Goodwood Formation, Grange Burn Formation at Muddy Creek (where they are always severely abraded) and Bairnsdale Limestone showed no differences.

(c) *Serripecten semilaevis* (McCoy); this species was redescribed under the name '*Lentipecten*' *adelaidensis* by Ludbrook (1955), and although her type material lacks radial sculpture, all the type material consists of RVs. All LVs and fragments of LVs from Dry Creek Sands bear the characteristic fine, close, scaly costellae of *Serripecten semilaevis*. Some moderately large fragments are available in a few bore samples, and we have no doubt that Ludbrook's species is synonymous with *S. semilaevis*.

All three of the above species are common also in Bookpurnong Formation in the outcrop at Wookool Bend, near Loxton, Murray River. This outcrop also is one of the few that contain both *Eotrigonia subundulata* (Jenkins) and *Neotrigonia acuticostata* (McCoy), indicating a late Middle to Late Miocene age (Darragh 1986: fig. 3). Ben McHenry (SAM) also has shown us a specimen of *E. subundulata* from Dry Creek Sands. Bookpurnong Formation also has been dated independently as Late Miocene–Early Pliocene by Foraminifera and dinoflagellates (Brown & Stephenson 1991; Macphail & Kellett 1993), with some evidence for a Late Miocene age. *Serripecten semilaevis* is common in Bookpurnong Formation, and is known by only one or two specimens from other localities younger than Bairnsdalian (six possible specimens from Black Rock Sandstone, Beaumaris, Cheltenhamian; NMV). *Mesopeplum subconvexum* appears, from the evidence of the localities cited below, largely to be limited to the Bairnsdalian Stage, with a few Mitchellian records. Most significant of all, though, is *Austrohinnites polyaktinos* which, apart from Dry Creek Sands, where it is usually found as the juvenile '*Chlamys* stage', is known only from the Bookpurnong outcrop. A complication, though, is introduced by *Mimachlamys asperrima*, which has not been collected from Bookpurnong Formation but is common and represented by spinose, 'young-looking' specimens in Hallett Cove Sandstone, Dry Creek Sands, Norwest Bend Formation, Goodwood Formation, Grange Burn Formation and both Cheltenhamian and Kalimnan parts of Jemmys Point Formation. At face value, this seems to indicate a Bairnsdalian age for Bookpurnong Formation (which clearly underlies Norwest Bend Formation in the Murray Basin) and a Mitchellian or, more probably, Cheltenhamian age for upper Dry Creek Sands, Hallett Cove Sandstone, Norwest Bend Formation and Goodwood Formation. Subject to confirmation from further evidence, we interpret this as indicating that *M. asperrima* occurs in *upper* Dry Creek Sands only, and this part of the 'formation' is post-Bairnsdalian, whereas other pectinids reported by Ludbrook are from the *lower* part of Dry Creek Sands, and are Bairnsdalian.

We conclude that the lower part of Dry Creek Sands is Bairnsdalian (late Middle Miocene) in age, thus the status of the Yatalan Stage (Ludbrook 1963) now becomes unclear. The diagram by Ludbrook (1963: fig. 4) is useful for understanding our concept of ages/faunas in the Dry Creek Sands; the lower fauna at about 105–115 m below sea level on her diagram is, in our opinion, probably coeval with the Bookpurnong marine incursion into the Murray Basin (Bairnsdalian). This age explains the otherwise anomalous occurrence in Dry Creek Sands of such gastropods, elsewhere limited to the Miocene, as *Sassia (Austrotriton) radialis* (Tate), *Ericusa ancilloides* (Tate) and *Nannamoria strophodon* (McCoy). The younger fauna, at about 80–60 m in Ludbrook's diagram, contains none of the diagnostic Miocene species, and appears likely to be coeval with Hallett Cove Sandstone on the coast near Adelaide, and with Norwest Bend Formation in the Murray Basin, ie., Late Pliocene. These correlations have the fewest possible disagreements with the ranges of pectinids in the Gippsland Basin and do away with the need for a faunal zone in the lower Dry Creek Sands that is recognised nowhere else in South Australia.

2. *Biostratigraphic distinction between the Murray River limestones:* For our work collecting pectinids from the Murray River limestones, we were fortunate to have the map by Lindsay & Giles (1973) distinguishing by means of Foraminifera the ages of the various sections. It has been known since the report by Ludbrook (1961) that the main, widespread formations cropping out along the river are Mannum Formation (Longfordian) and Morgan Limestone (Balcombian). In most places there is therefore a short hiatus between these two formations in most places representing the Batesfordian Stage, although a Batesfordian marl unit, Finniss Clay, can be seen between them at a few places (Mannum pumping station; Ludbrook 1961). The ages of these units recently have been confirmed by Li & McGowran (1999). It should be noted, though, that Lukasik & James (1998) provided a new, more finely divided litho-stratigraphy for Murray Group (which they raised

to a supergroup), recognising distinct Bryant Creek Formation and Glenforslan Formation for Morgan Limestone (now recognised as a group) above and below Cadell Marl (Formation), respectively, subdividing Mannum Formation into upper and lower members, and recognising several members within both Cadell and Finniss formations. As we collected pectinids before this subdivision was recognised, and are unable to relate our localities to the new subdivisions without further field work, we have retained here the lithostratigraphy proposed by Ludbrook (1961). The two main limestone formations (Mannum Formation and Morgan Limestone) are similar in general appearance, although a soft, white upper bed in Morgan Limestone is distinctive; the bulk of both units is hard, yellow to brownish yellow, and rich in echinoids. Visual distinction between these units is therefore difficult when the white upper bed of Morgan Limestone is not present in the outcrop. Having collected with the foreknowledge of age from Foraminifera, we are able to offer some significant biostratigraphic differences that are easily recognised in the field between the two limestone formations. Although both formations contain *Semipallium foulcheri* (in great numbers), *Serripecten yahliensis* (in small numbers) and *Mimachlamys sturtiana*, the other scallops present are limited to one or the other of these units:

(a) Mannum Formation contains: *Serripecten squamocostatus*, *Talochlamys eyrei*, *Victoripecten victoriensis*, *Annachlamys rhipidata*, *Mesopeplum minimum* and *Amusium subcostatum*;

whereas

(b) Morgan Limestone contains: *Talochlamys laticostata*, *Annachlamys murrayana*, *Mesopeplum incertum* and *Amusium morganense*.

Although not all these species are common (for example, *Amusium subcostatum* and *Annachlamys rhipidata* are known from Mannum Formation in small numbers and from only a few localities), all are congeneric species pairs except the distinctive, coarsely sculptured Mannum Formation species *Serripecten squamocostatus* and the equally distinctive *Victoripecten victoriensis*, smooth both inside and out and also limited to Mannum Formation. Scallops therefore provide a very ready separation of these formations wherever they are found. Further carefully located collections may well demonstrate that some pectinids are limited to the finer subdivisions of these formations recognised by Lukasik & James (1998).

3. *Relative ages of Black Rock Sandstone and Tambo River Formation:* Black Rock Sandstone at Beaumaris, near Melbourne, and Tambo River Formation in Gippsland contain quite similar pectinid assemblages, indicating at least a similarity in age. Taxa common to the two formations are *Serripecten carteri* (although there is some doubt about the identity of the poorly preserved Black Rock specimens), *Austrohinnites corioensis*, *Mimachlamys asperrima* and *Mesopeplum divergens*; these are the only formations from which we record *M. divergens*. Black Rock Sandstone also contains *Serripecten semilaevis*, which we have not seen from Tambo River Formation, and Tambo River Formation also contains *Talochlamys keiloriana*, which we have not seen from Black Rock Sandstone. Even within Tambo River Formation there is a distinction between outcrops, as the Lake Tyers locality has *T. keiloriana* but not *M. asperrima* or *A. corioensis*, whereas the Swan Reach locality has yielded *A. corioensis* and very abundant *M. asperrima*, but lacks *T. keiloriana*.

These two formations are Late Miocene in age; Black Rock Sandstone is the stratotype of the Cheltenhamian Stage, whereas Tambo River Formation is the stratotype of the Mitchellian Stage. Uncertainty over many years about the relative ages of these widely separated units was resolved by Wilkins (1963), who demonstrated that the Cheltenhamian lower Jemmys Point Formation overlies the Mitchellian Tambo River Formation in Gippsland. The similarities and rather surprising differences between the pectinid assemblages in the two formations, and even between outcrops of Tambo River Formation, do not provide as much substantiation of their relative ages as might have been expected. The differences seem to indicate that subtleties of the depositional environment, perhaps including substrate grainsize and water turbidity, may play a significant role in determining the pectinid assemblage present at any one locality. These differences inject a note of caution into the interpretation of pectinid biostratigraphy.

ABBREVIATIONS

Throughout this work, we use the following abbreviations for instruments, for parts of the pectinid shell, and for the institutions housing the material studied:

AGSO	Australian Geological Survey Organisation, Canberra; houses the Commonwealth Paleontological Collection (CPC)
AK	Auckland Institute and Museum, Auckland
AMS	Australian Museum, Sydney

BMNH	Natural History Museum, London; formerly British Museum (Natural History)
CPC	Commonwealth Palaeontological Collection (see under AGSO, above)
GSWA	Geological Survey of Western Australia, Perth
H	*height of the shell (see Fig. 1)*
IGNS	Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand; formerly New Zealand Geological Survey (non-New Zealand collections prefixed 'WM')
L	length of the shell (see Fig. 1)
LV	left valve
MHNG	Muséum d'Histoire Naturelle de Genève, Geneva
MNHN	Muséum National d'Histoire Naturelle, Paris
NMV	Museum Victoria, Melbourne
PL	Museum Victoria fossil locality number (see localities listed in the Appendix)
RV	right valve
SAM	South Australian Museum, Adelaide
SEM	scanning electron microscope, scanning electron micrographs
V	valve (one half of a bivalve shell)
WAM	Western Australian Museum, Perth.

Figure captions. In the figure captions, all specimens are assumed to be in NMV (registration numbers prefixed 'P'), unless stated otherwise. Other repositories are indicated by the abbreviations listed above (nearly all are in either SAM or WAM).

LOCALITY LISTS

To abbreviate the locality data as much as possible, all collections are assumed to be housed in Museum Victoria and all localities are assumed to occur in Victoria unless otherwise stated, and most localities are abbreviated in the lists under each species to their PL numbers (Museum Victoria fossil locality numbers) and a brief locality descriptor. The details of PL localities are listed in the Appendix. Locality details are given for some of the material from museums other than Museum Victoria (almost all in either WAM or AMS, apart from Tate's types, in SAM), but these have been condensed with other collections where possible to save space.

SYSTEMATICS

Family Pectinidae Wilkes, 1810

Pectinoidea with a single symmetrical triangular resilifer in the centre of the hinge, with weak, low hinge teeth in the form of radial ridges on each side of the resilifer, ie., not the prominent isodont hinge of Spondylidae, and with a true ctenolium (at least in the juvenile), forming a succession of younger ctenolial teeth as the byssal notch progresses down the anterior margin of the growing right valve. The shell is composed mostly of calcite, with a thin inner layer of aragonite, limited to inside the pallial line in Cenozoic and Recent Pectinidae, and with an aragonitic myostracum.

Subfamily Camptonectinae Habe, 1977

Pectinidae without prominent, true radial sculpture, so that the regular, evenly spaced antimarginal ridgelets ('*Camptonectes* microsculpture') form the most obvious sculpture; posterior auricles not clearly demarcated from the disc. Small, thin, and in most cases glassy, translucent scallops, most taxa in the present day limited to the deep sea (eg., Grau 1959: 38–55). In Cenozoic and present-day faunas, represented by the single relict genus *Delectopecten* (Waller 1991: 13). Representatives of this subfamily are mainly Mesozoic and the diagnosis applies only to Cainozoic faunas.

Genus ***Delectopecten*** Stewart, 1930

Delectopecten Stewart, 1930: 118.

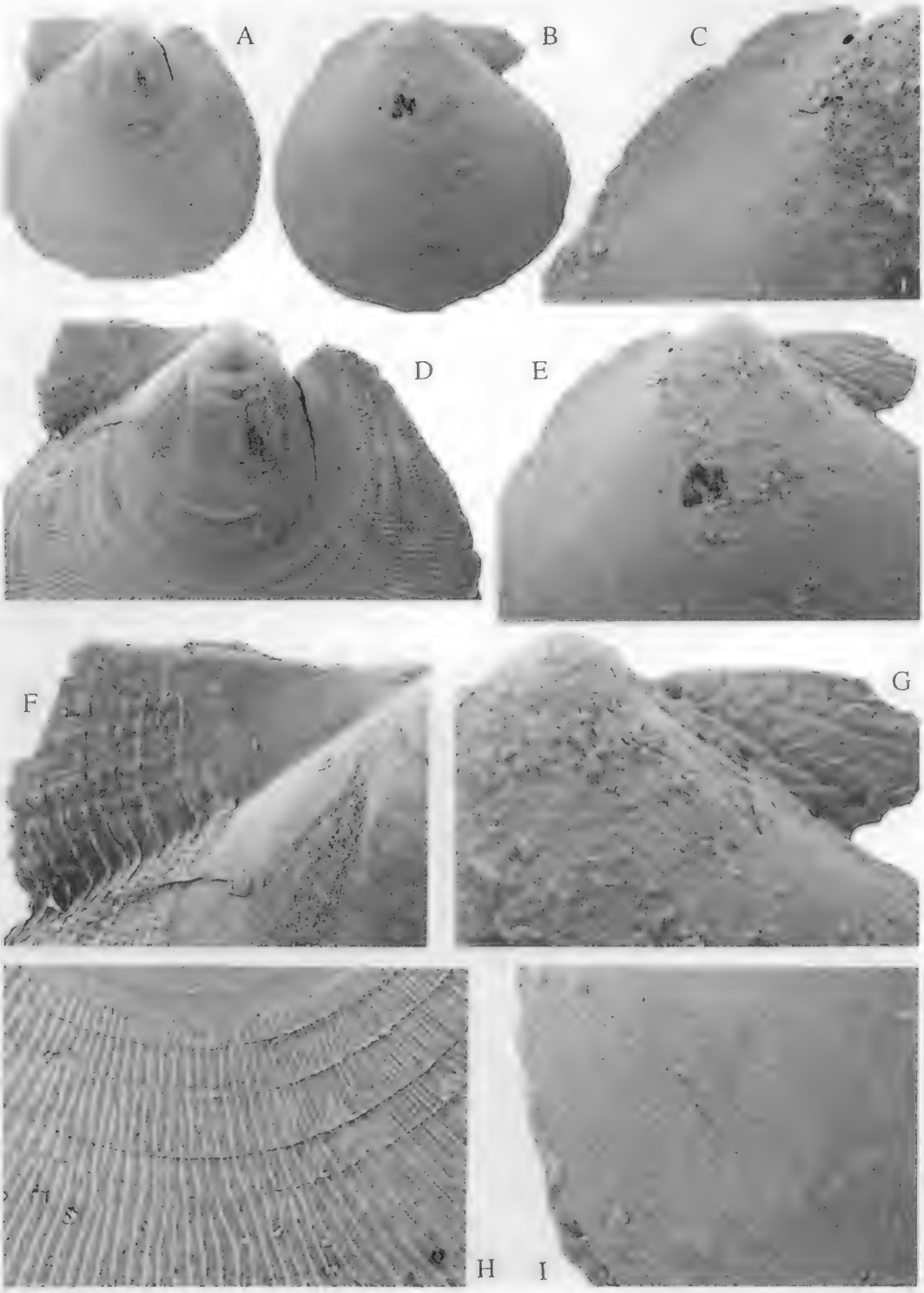
Type species (by original designation). *Pecten (Pseudamussium) vancouverensis* Whiteaves, 1893. Recent, western Canada.

Delectopecten crassistriatus sp. nov.

Fig. 7A–I

Delectopecten sp. Darragh, 1997: 103, fig. 12L.

Description. Small for genus (H 4.8, L 5.2; largest fragmentary paratype 7.6 mm long), rather strongly inflated. Disc acline, almost circular, slightly taller than long. Prodissoconch remaining on umbo of LV (holotype) and presumably on RV, but abraded on available RVs. LV sculpture of many low, narrow, flat-topped, closely spaced, slightly wavy antimarginal ridgelets, crossed by low, very narrow, widely spaced commarginal lamellae with interspaces the width of about 3–5 antimarginal ridgelets. Commarginal lamellae more closely spaced over anterior auricle than on disc, raised into low folds where they cross antimarginal ridgelets, so producing 8 weakly defined radial costellae on anterior auricle only; commarginal lamellae particularly prominent in groove separating auricle from disc. Sculpture of examined RV paratype of much lower and less continuous antimarginal ridgelets than on LV, but apparently significantly abraded; commarginal sculpture apparently not


A
B
C
D
E
F
G
H
I

present on LV. Anterior auricle strongly demarcated from disc by deep groove and deep, V-shaped byssal notch; no ctenolium observed, apparently abraded. Auricle bearing 7 prominent, wide, closely spaced radial costellae, crossed by about 15 prominent, wide commarginal ridges, forming low nodules where they cross costae. Internal characters not seen.

Dimensions. Holotype, P301766 H 4.0 L 3.7 LV
Paratype, P302786 4.8 5.2 RV

Type material. Holotype, NMV, P301766, Pebble Point Formation, Paleocene, PL3003, fallen blocks in cove between Buckley Pt and Pt Pember, 4.5 km SE of Princetown, Victoria, coll. T. A. Darragh, 13.xii.1994; figured paratype, P302786, and 3 incomplete paratypes, P302787–9, from same locality as holotype.

Time range and occurrence. Type locality only (9 specimens and fragments); Late Paleocene.

Remarks. *Delectopecten crassistriatus* sp. nov. differs from almost all other species of *Delectopecten* we are aware of in its small size, its strong inflation, and its prominent radial costellae on the anterior auricles, particularly on the RV. The only similar species we are aware of is *D. musorstomi* Poutiers (1981), living throughout the western Pacific from the Philippine Islands to Norfolk Island and New Caledonia, in 130–500 m (Dijkstra & Marshall 1997: 88, pl. 8, figs 1–6). *D. musorstomi* is similar in size to *D. crassistriatus* and has a similarly sculptured but longer RV anterior auricle, but is slightly prosocline in shape and has coarser and more complex disc sculpture than *D. crassistriatus*. Dr T. R. Waller (1999, pers. comm.) has pointed out that many other Paleogene *Delectopecten* species (although in many cases not as yet referred to this genus) are similar to *D. crassistriatus* sp. nov. in their small size and in their strongly costate RV anterior auricle, eg., *Pecten (Pseudamussium) alternilineatus* Clarke (1918: 132, pl. 13, figs 14, 15). This species is described as 5.5 mm high and 5.0 mm long, with the RV anterior auricle 'covered by about five subnodose to spinose radiating lines'. However, this species, and all others we know of, clearly differ from *D. crassistriatus* sp. nov. in their much lower inflation ('diameter of both valves, 0.75 mm'; Clarke 1918: 132). It seems likely that the more prominent sculpture on the disc of the LV than on the RV of *D. crassistriatus* is a real character of the new species, although it is possibly due to abrasion of the examined RV; slight differences in sculpture between the two valves occur in some other species of *Delectopecten* [eg., *D. vitreus* (Gmelin); Grau 1959: pl. 18]. This is the only fossil species of *Delectopecten* we are aware of in Australia or New Zealand; the only other species recorded from the region is the New Zealand living *Delectopecten fosterianus* (Powell) (Powell 1933: 370; 1979: 379, pl. 73, fig. 3), which differs from *D. crassistriatus* in its much larger size (to 20 mm high) and weaker sculpture. *D. fosterianus* is sculptured only with weak antimarginal ridgelets and sparse, ventrally cupped scales. Although *Delectopecten* is largely an abyssal taxon at present, some species were recorded by Grau (1959) from the inner shelf, and it need not indicate a deep-water element in the Pebble Point fauna. Indeed, the surprisingly good preservation of these tiny, fragile shells in the coarse-grained Pebble Point Formation attests to their derivation from a nearby location in shallow water, though the preservation is not complete enough to detect the presence of a ctenolium. Dr T. R. Waller has also pointed out (1999, pers. comm.) that *Delectopecten* is among many taxa occurring in deep water at low latitudes, but living in shallower water nearer the poles. The living eastern Pacific *D. vancouverensis* (Whiteaves), for example, has been collected in 18–40 m near Vancouver Island, British Columbia (Grau 1959: 41).

Etymology. The specific name (Latin, '*crassus*', coarse, +'*striatus*', grooved) refers to the relatively coarse sculpture of this species.

Subfamily Pectininae Wilkes, 1810

Diagnosis. Pectinidae with prominent, truly radial costae as well as antimarginal ridgelets, and with both anterior and posterior auricles clearly separated from the disc by a groove.

Remarks. As noted above under 'Classification', we include all the large, radially costate Australian Cenozoic fossil pectinids in the one subfamily

Fig. 7. *Delectopecten crassistriatus* sp. nov., Paleocene, Pebble Point, Victoria. A, D, F, H, holotype, LV, P301766, 4.0 × 3.7 mm: A, whole shell, × 10; D, F, anterior auricle, × 25 and × 55; H, sculpture in lower centre of disc, × 55. B, C, E, G, I, paratype, RV, P302786, 4.8 × 5.2 mm; B, whole shell, × 9.4; C, posterior auricle, × 33; E, G, anterior auricle, × 20 and × 40; I, sculpture near posterior ventral margin, × 40.

Pectininae, on the advice of Dr T. R. Waller. These are assigned to six Tribes, representing 16 of the 17 genera comprising the study material.

Tribe **Chlamydini** Teppner, 1922

Remarks. A diagnosis of the tribe is provided above, under 'Classification'. Chlamydini contains all scallops with shagreen microsculpture, although by no means all genera of Chlamydini retain shagreen microsculpture at the present time. The members also are easily recognised by their irregularly subdivided or intercalated secondary and tertiary radial costae, so that the costae increase markedly in number as the shell grows. This is in obvious contrast with all other Pectininae, in which the major radial costae remain fixed in number (undivided) across the entire disc. Most members also retain antimarginal microsculpture across most or all of the shell, although the antimarginal ridgelets are not present on the LV preradial dissoconch of some taxa, so that the LV preradial dissoconch sculpture is modified in various ways, and in many Australian taxa is quite weak or almost absent. All members also have relatively insignificant hinge teeth, all of which are parallel either to the dorsal hinge margin or to the margins of the resilifer. Finally, almost all members retain the chlamydoid shell form, with a prosocline disc and a long RV anterior auricle and deep byssal notch, at least in their early stages, ie., they live byssally attached to hard objects, although adult specimens of some taxa are free-lying and lose the functional byssus. All the hinnitoid, cemented pectinids seem to have been developed by members of this tribe, or by offshoot tribes such as Crassadomini Waller, 1993.

This is much the most diverse group of scallops in both Australia and New Zealand. Such a composition is perhaps a reflection of the southern, temperate location of these landmasses, as most taxa of other tribes tend to occur in tropical waters. There is a marked contrast, though, between Australia and New Zealand in some aspects of the composition of the tribe; for example, taxa with shagreen microsculpture predominate in Australia (present in *Austrohinnites*, *Equichlamys*, *Notochlamys*, *Semipallium*, and some species referred to *Talochlamys*; a total of at least 12 species) whereas only *Austrohinnites*, *Athlopecten athleta*, and the Paleocene '*Chlamys*' *mercuria* Marwick (Beu & Maxwell 1990: 90, pl. 4e, f) have shagreen microsculpture in New Zealand (5 or 6 species). The most notable point is that, with the exception of *Mimachlamys asperrima*, *M. heterophyseta* and *M. sturtiana*, *Annachlamys murrayana*, and the species of *Mesopeplum* and *Amusium*, Tribe Chlamydini includes all the common, widespread scallops in southern Australian Cenozoic rocks, as well as in the southern Australian living fauna.

Genus ***Abrachlamys*** gen. nov.

Type species. *Abrachlamys toolinnensis* sp. nov., Early Miocene, Eucla Basin, Western Australia.

Diagnosis. Chlamydini of rather wide, short, aequipectinoid shape, retaining a deep, narrow byssal notch and chlamydoid RV anterior auricle in adults; valves about equally inflated; radial sculpture of almost fixed number of undivided costae, few costal subdivisions seen on some specimens; with antimarginal ridgelets over all intercostal surfaces, and on disc margins and auricles; radial costae and auricles of LV bearing numerous, regularly and widely spaced, low commarginal lamellae, about 1 mm apart in centre of disc, raised into low scales on costal crests, weakly continuous across radial interspaces; on RV, identical lamellae to those of LV present only on auricles and on few, narrower, more closely spaced costae on anterior and posterior ends of disc, costae on most of RV disc smooth apart from antimarginal ridgelets; internal expressions of external costae are merely corrugations, without internal rib carinae. One low, narrow intermediate tooth on each side of hinge in one RV; not seen on other material. LV preradial sculpture not known.

Remarks. The new genus is proposed for a single species that does not fit well into any genus of Pectinidae with which we are familiar. Clearly chlamydinine characters displayed by *Abrachlamys toolinnensis* gen. nov., sp. nov. are the lack of internal rib carinae (although that could occur in primitive members of almost any tribe), the presence of dominant antimarginal ridgelets over all the shell surface and the retention of the chlamydoid deep byssal notch and ctenolium in the adult. The rather wide, aequipectinoid shape is unusual for a member of the Chlamydini, but is seen in some other undoubted members such as *Serripecten*, *Equichlamys*, and *Talochlamys* species of the *T. keiloriana* species group (including the Abrakurrie Limestone species *T. multilamellata*). The commarginal lamellae might be taken for those of the Palliolini, were it not that they are absent over most of the RV, and are spaced about 1 mm apart over the central area of the LV disc, much more widely apart than the normal microsculpture

of Palliolini. The little-divided radial costae also are an unusual character for a member of the Chlamydini, and the presence of what appear to be intermediate hinge teeth in one specimen is an anomalous character for the Chlamydini. The lack of knowledge of most other phylogenetically useful characters makes it difficult to assess the relationships of *Abrachlamys*, particularly not knowing the LV preradial microsculpture, but the balance of characters and, in particular, the persistent antimarginal ridgelets, indicate a position in Chlamydini. Dr T. R. Waller has pointed out (1999, pers. comm.) that many species of Eocene and Oligocene age from Europe and the eastern USA are very similar to *Abrachlamys toolinnensis* gen. nov., sp. nov. in many characters—in their broad shape, with umbonal angles greater than 90°, in their deep byssal notch, in their relatively simple costae that show only a slight tendency to increase in number during ontogeny, in their low convexity, in their costate disc flanks, in their commarginal lamellae lacking the ventrally convex intercostal flexure of the *Aequipecten* pattern, and in lacking internal rib carinae. It appears likely, then, that species related to *Abrachlamys*, and possibly congeneric with it, are widespread in Paleogene rocks. However, study of and comparison with these extra-Australian species is beyond the scope of this revision.

A possible second Australian species of *Abrachlamys* seems to be represented by specimens illustrated by Ludbrook (in Lowry 1970: fig. 21A, E) under the names '*Chlamys* cf. *sturtianus*' [*sic*] and '*Chlamys eyrei*'. These specimens are from 'Toolinna Limestone' (a local facies of the Eocene Wilson Bluff Limestone or possibly Abrukurrie Limestone according to Li et al. 1996) at Toolinna Cove, Great Australian Bight, and are housed by GSWA. More material is needed before this taxon can be evaluated.

Etymology. The generic name (Abrakurrie + *Chlamys*) refers to the formation, Abrakurrie Limestone, that was the provenance of the type species. Gender feminine.

Abrachlamys toolinnensis sp. nov.

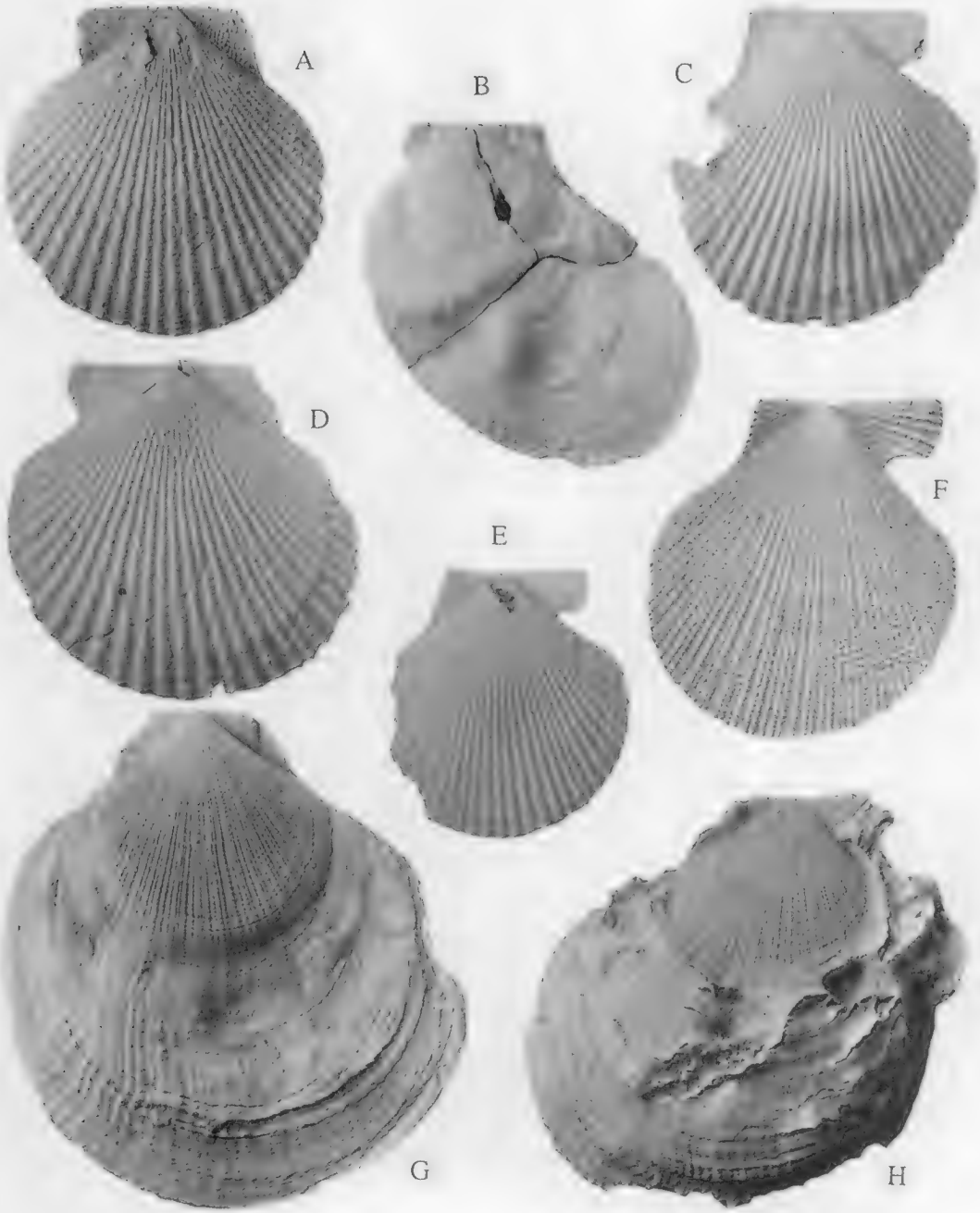
Fig. 8A, C–E

Description. Moderate-sized (to *c.* 39 mm high and 40 mm long), length slightly greater than height in moderate-sized to large specimens, shape acline in most specimens, very weakly prosocline in a few; umbonal angle *c.* 115° in large specimens; posterodorsal margin similar in length to anterodorsal margin, but inclined ventrally at a slightly steeper angle, posterior auricles therefore a little taller than anterior auricles. Radial sculpture of 28–30 moderately elevated, moderately wide, round-topped costae, each interspace the same width as one costa; most costae undivided over whole height of most specimens, but a few costae subdivided into extra costae on some specimens, where they rise in prominence to equal primary costae by valve margin; increase is by rib-flank bifurcation on LV (Fig. 8D; one bifurcation clearly visible at posterior third of disc length) and by medial intercalation on RV, although less common on RV than on LV. Disc flanks low, steep (ie., narrowly rounded), with many narrow, closely spaced radial costellae. Commarginal sculpture of low lamellae, *c.* 1 mm apart over centre of LV disc, elevated slightly to form low scales on costal crests, but very low and straight across costal interspaces, present over entire LV, but on RV present only on auricles and on 2–3 narrow costae on anterior and posterior ends. Entire surface, where not more coarsely sculptured, bears fine, closely spaced antimarginal ridgelets only. RV anterior auricle long and narrow, with deep, wide byssal notch persisting in adults; byssal fasciole depressed, its outer margin inclined dorsally towards posterior so that auricle narrows posteriorly; presumably with functional ctenolium, but teeth not observed; main outer face sculptured with 4–5 prominent, scaly radial costae as on disc; commarginal lamellae raised into prominent, thin serrations along dorsal margin of both RV auricles. LV anterior auricle moderately tall, sculptured as on disc, with weakly sinuous anterior margin inclined moderately strongly towards anterior and dorsum. Posterior auricles moderately tall, sculptured as on disc, posterior margin of both slightly concave, inclined slightly towards anterior. Other characters as for genus.

Dimensions.

Holotype, WAM 68.348	H 30.8	L 29.9	LV
Largest paratype, WAM 78.3951a	38.6	39.7	LV
Paratype, WAM 78.3951b	34.8	36.0	LV
WAM 78.3951c	29.4	29.3	RV
WAM 78.3952a	32.2	33.5	LV
WAM 78.3952b	28.3	28.4	RV

Type material. Holotype, WAM 68.348, Abrakurrie Limestone, Longfordian, cliff face at Toolinna, south of Caiguna, Eucla Basin, Western Australia, coll. P. J. Bridge, 1967; this is the only specimen of *Abrachlamys toolinnensis* sp. nov. that has been collected weathered out on an exposure, rather than removed from a block of hard limestone, and so is by far the most suitable specimen to be the holotype. Li et al. (1996) identified the limestone at Toolinna Cove as Abrakurrie Limestone,


A
B
C
D
E
F
G
H

based on foraminiferal biostratigraphy, and this assignment is confirmed by the very close similarity of the holotype of *A. toolinnensis* to specimens from more inland outcrops. James & Bone (1994) had earlier mapped 'Oligocene–Early Miocene' Abrakurrie Limestone reaching a thickness of more than 30 m at Toolinna Cove, and showed pectinids (apparently *A. toolinnensis*) occurring abundantly in outcrop (James & Bone 1994: fig. 8a). WAM 78.3951, Abrakurrie Limestone, roof fall in eastern extension of Mullamullang Cave, Madura district, southeastern Western Australia, coll. G. W. Kendrick, 21.v.1978, 6 paratypes removed from a block of firm, yellow limestone; WAM 78.3952, Abrakurrie Limestone, all data as for WAM 78.3951, 2 paratypes and *c.* 12 less complete specimens removed from a block of firm yellow-orange limestone, plus numerous fragmentary specimens remaining in pieces of rock; WAM 99.499, Abrakurrie Limestone, spoil from well at ruin, Moodini Bluff, 23 km E of Madura Roadhouse, at foot of Hampton Escarpment, Madura district, southeastern Western Australia, map ref. Madura 530054, coll. T. A. Darragh, M. Archer, G. W. Kendrick, 5.iii.1969; 2 paratypes and 3 fragmentary specimens removed from a block of hard, cream-fawn limestone. These specimens were removed from the same block as the type material of *Talochlamys multilamellata* sp. nov.

Occurrence and time range. Known only from Abrakurrie Limestone (Longfordian), Eucla Basin, southeastern Western Australia.

Remarks. The distinctive combination of characters seen in *Abrachlamys toolinnensis* gen. nov., sp. nov., will make it easily recognised, and there are really very few pectinids from Australia or New Zealand it can be compared with. As noted above, Dr T. R. Waller (1999, pers. comm.) has indicated that many European and eastern North American Eocene and Oligocene pectinids closely resemble *A. toolinnensis*, eg., '*Pecten*' *plebeius* Lamarck, 1806 (illustrated, as *Lyropecten (Aequipecten) plebeius*, by Glibert 1976: 40, pl. 2, fig. 4a, b), and it is likely that this is a widespread Paleogene genus-group. '*P.*' *plebeius* is much less scaly than *A. toolinnensis* sp. nov., and seems to lack the discrepancy between the valves in scale development that is so characteristic of the present species. *A. toolinnensis* occurs in Abrakurrie Limestone with *Talochlamys multilamellata* sp. nov., and some of the paratypes and other specimens listed above were removed from the same block as all the known material of *T. multilamellata*. They were immediately separable while being removed from the rock, because of the slightly greater inflation of *A. toolinnensis*, the lack of commarginal sculpture over almost all of the RV of *A. toolinnensis*, compared with consistent commarginal lamellae on both valves in *T. multilamellata*, and the much more frequently and finely subdivided radial costae, and the resulting much frillier sculpture in general, of *T. multilamellata*. The fixed number of radial costae, or at most with a few costae very weakly subdivided on a few specimens, the persistence of antimarginal ridgelets across the entire RV, the wide, aequipectinoid shape which, however, retains a deep byssal notch in the largest specimens seen, the thin and fragile shell, and the widely spaced, rather prominent commarginal lamellae on the LV but its absence over most of the RV are the diagnostic characters of the new genus and species.

Etymology. The specific name ('from Toolinna') refers to the type locality of the species, Toolinna Bluff.

Genus ***Austrohinnites*** gen. nov.

Type species. Hinnites corioensis McCoy, 1879, Late Oligocene to Late Miocene, South Australia, Victoria and Tasmania.

Diagnosis. Chlamydini with a byssally attached, *Chlamys*-like juvenile stage and a thick, oyster-like adult stage RV cemented to hard substrates and growing into an irregular shape in conformity with the substrate; '*Chlamys* stage' bearing prominent, coarse shagreen microsculpture; LV preradial dissoconch with microsculpture of very weak, antimarginally aligned pits and weak, widely spaced radial and commarginal ridges.

Fig. 8. A, C–E, *Abrachlamys toolinnensis* sp. nov., type species of *Abrachlamys* gen. nov., Abrakurrie Limestone (Longfordian), Eucla Basin, Western Australia, all × 1.25: A, holotype, LV, WAM 68.348, cliff face at Toolinna, Great Australian Bight; C, WAM 78.3952b, paratype RV, and D, WAM 78.3952a, paratype LV, Mullamullang Cave, Madura district; E, WAM 99.499a, paratype RV, spoil from well at ruin, Moodini, 23 km east of Madura roadhouse, at foot of Hampton Escarpment. B, *Austrohinnites corioensis* (McCoy), type species of *Austrohinnites* gen. nov., lectotype (designated here) of *Hinnites mulderi* Chapman, LV, P59353, Batesford Limestone (Batesfordian), Batesford quarry, near Geelong, Victoria, 'pres. J. F. Mulder, 7 Oct. 1914'; natural size. F–H, *Austrohinnites polyaktinos* (Ludbrook), South Australia: F, holotype of *Chlamys polyaktinos* Ludbrook, RV, SAM F15120, lower Dry Creek Sands (Bairnsdalian), Abattoirs Bore, Adelaide, × 2; G, LV, P302060; and H, RV, P302061, Bookpurnong Formation (Bairnsdalian), Wookool Bend, near Loxton, Murray River, natural size.

Remarks. It has long been unclear whether the large group of species traditionally included in *Hinnites* Defrance,1821 (type species: *Ostrea crispa* Brocchi, 1814, Pliocene, Italy; ?living, West Africa) is a monophyletic genus of cemented, oyster-like scallops, or a group of unrelated taxa lumped together on the basis of superficial morphology, representing several or many independent lineages that each developed an oyster-like habit from a *Chlamys*-like ancestor. An opinion favouring the latter alternative was expressed long ago by Dall (1908: 402). Bernard (1986) and Waller (1991: 22–23; 1993: 203–204) have reviewed the phylogenetic relationships of *Hinnites*-like pectinids. '*Hinnites*' *giganteus* (Gray), living, northwestern North America, was provided with its own genus, *Crassadoma*, by Bernard (1986). Waller (1993) indentified a group of eastern Atlantic and eastern Pacific species that resemble *C. gigantea* closely in all characters other than having a cemented, ostreoid adult stage, and placed them all in *Crassadoma*, in its own tribe Crassadomini Waller, 1993; a new genus, *Caribachlamys* Waller, 1993, was also referred to Crassadomini. True *Hinnites*, including *H. crispus* (Brocchi) and the possibly synonymous, living West African *H. corallinus* (G. B. Sowerby I, 1828) (see Waller 1993: 203–204, for the complex nomenclatural history of this species) lacks shagreen microsculpture, and was thought by Waller (1993: 203) to be descended from *Laevichlamys* Waller, 1993. Contrary to the opinion of Dijkstra & Matsukuma (1993), *Chlamys ('Hinnites') boninensis* Dijkstra & Matsukuma, 1993 appears to lack true shagreen microsculpture, and clearly bears antimarginal ridgelets on the costae and interspaces of the '*Chlamys* stage'. This southern Japanese species belongs in *Laevichlamys* Waller, 1993 (H. H. Dijkstra 1999, pers. comm.). *Pseudohinnites* Dijkstra (1989) is another superficially similar but (to judge from its unusual, dorsally contracted auricles and distinctive, prominent radial sculpture) probably again independently evolved genus, living in deep water in New Caledonia and the Caribbean. Dijkstra & Knudsen (1997) recently showed that *Pseudohinnites* retains a very deep byssal notch and a functional ctenolium throughout life. Apparently it is not cemented to the substrate, and in the opinion of Dr T. R. Waller (1999, pers. comm.) belongs in the Pectinidae and actually is better not thought of as 'hinitoid'. Harper (1991) discussed the role of predation in the evolution of the many, Paleozoic to Recent, independently evolved, cemented bivalves superficially resembling *Hinnites*.

The large, common Australian fossil '*Hinnites*' *corioensis* McCoy is one of a group of Australian and New Zealand species sharing the distinctive characters of coarse, obvious, persistent shagreen microsculpture on the '*Chlamys* stage' and, in some specimens, persisting onto the early cemented stage, and a distinctive, extremely weakly sculptured to virtually smooth LV preradial dissoconch. This therefore appears to be a monophyletic group, distinct from all other species referred previously to *Hinnites*. Following Waller's (1993) example, it would seem logical to refer this group to the genus from which the cemented species were derived, but it is not at all clear what that genus was. Other Australian and New Zealand chlamydinine taxa with coarse shagreen microsculpture and very weak LV preradial dissoconch microsculpture are *Equichlamys*, which appears in Australia late in Pliocene time, after the '*Hinnites*' *corioensis* species group had become extinct, and *Notochlamys*. *Notochlamys* is assigned an Eocene (provisional) to Recent time range in Australia in the present work, but this is largely an artifact of not knowing the true phylogenetic relationships of the two pre-Pliocene species referred there. Undoubted *Notochlamys* is, again, a Pliocene to Recent genus, and we have not seen the LV preradial dissoconch sculpture of the pre-Pliocene species referred there. The only other possibly related species is '*Chlamys*' *mercuria* Marwick, 1928 (Beu & Maxwell 1990: pl. 4e, f) from latest Paleocene–earliest Eocene rocks of Chatham Island. This small (12–20 mm high), chlamydoid species shares shagreen microsculpture with *Austrohinnites*, and provides a possible early member of the same phylogenetic group. The prominently and irregularly subdivided radial costae of the '*Hinnites*' *corioensis* species group is a character that distinguishes it clearly from both *Equichlamys* and *Notochlamys*, as much as from all the other taxa described below. We do not know the origins of the '*Hinnites*' *corioensis* species group, and as it has been a distinct phylogenetic unit in Australasia since at least Late Eocene time, it seems best recognised as a separate Australasian genus, *Austrohinnites*. The living North Pacific species *Hinnites boninensis* (Dijkstra & Matsukuma) obviously is not related to *Austrohinnites*, but the living West African '*H*'. *ercolanianus* Cocconi, 1873 and its European Miocene–Pliocene ancestors (Waller 1993: 202) have shagreen microsculpture, and the possibility that they are descended from *Austrohinnites* deserves investigation.

Etymology. The prefix of the name (Latin, '*austral*' = southern, + *Hinnites*) refers to the Southern Hemisphere occurrence of the included species. Gender masculine.

Species included in *Austrohinnites* gen. nov. at present are:

Austrohinnites corioensis (McCoy, 1879), Late Oligocene to Late Miocene; revised below.
Austrohinnites marwicki (Allan, 1946), Middle Miocene, New Zealand.
Austrohinnites polyaktinos (Ludbrook, 1955), Middle Miocene; revised below.
Austrohinnites trailli (Hutton, 1873), late Early Miocene, New Zealand.
Austrohinnites sp. nov.?, early Early Miocene, New Zealand.
Austrohinnites sp. nov.?, Late Eocene, New Zealand.

Austrohinnites corioensis (McCoy, 1879)

Figs 8B, 9A–E, 10A–E

Hinnites corioensis McCoy, 1879: 31, pl. 38; Tate, 1886: 116; Tate, 1899: 272; Dennant & Kitson, 1903: 120; Crespin, 1950: 152, pl. 15, fig. 13.
Pecten deformis Tate, 1887d: 185, pl. 18, fig. 4 (junior homonym of *Pecten deformis* Gabb, 1864).
Hinnites tatei Cossmann, 1907: 201 (new name for *Pecten deformis* Tate, preoccupied).
Hinnites mulderi Chapman, 1922: 5, pl. 2, figs 9, 10.

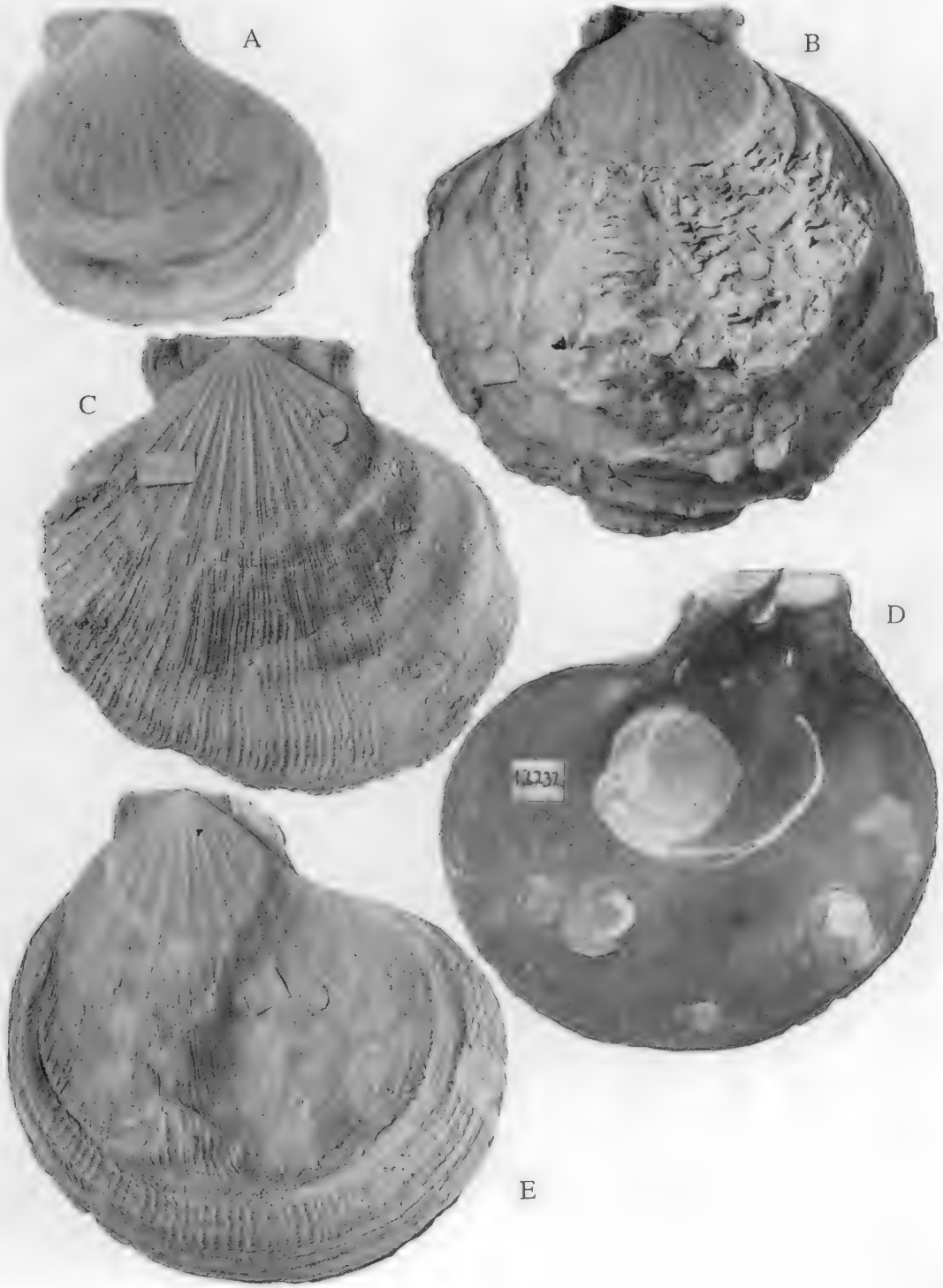
Description. '*Chlamys* stage' very weakly inflated, with moderately wide umbonal angle (*c*. 110°), acline to weakly prosocline; exterior sculpture of 10–14 narrow, widely spaced primary radial costae, increasing in number rapidly and irregularly across disc through intercalation and minor subdivision, to reach up to 75 highly irregular, narrow to moderately wide, convex-topped costae near ventral margin of large specimens; costal crests bearing many low, closely spaced, ventrally directed scales; interspaces closely sculptured with coarse, prominent shagreen microsculpture. RV anterior auricle long and narrow, with deep byssal notch; LV anterior auricle long, tall, with weakly sinuous anterior margin, inclined weakly towards anterior at dorsal margin; posterior auricles small, short, with weakly concave posterior margins. At disc height of *c*. 15–60 mm, becoming cemented to hard substrates, thickening greatly to adopt ostreoid form, weakly to very strongly prosocline, LV weakly inflated, RV moderately strongly inflated to deeply cupped; large specimens (to 120 mm high and 110 mm long) developing wide resilial area and elongate, prosocline resilifer. Exterior sculptured with many low, widely spaced radial costae bearing many low, wide to semitubular, ventrally directed scales, in many specimens little different from sculpture of '*Chlamys* stage', although relatively much weaker; many RVs developing highly irregular, foliaceous, wide, roughly commarginal attachment lamellae.

Dimensions.

Lectotype of *Hinnites corioensis*			
P12232	H 73.8	L 74.7	LV
Paralectotype of *Hinnites corioensis*			
P12229	62.0	70.9	LV
P12230	69.0	71.8	LV
P12231	81.1	79.5	RV
P12171	77.0	73.1	RV
Lectotype of *Hinnites mulderi*			
P59353	49.6	49.0	LV
Lectotype of *Pecten deformis*			
SAM T999A	47.0	47.0	LV

Type material. *Hinnites corioensis* McCoy, 1879, lectotype designated here, NMV P12232, Fyansford Formation, Corio Bay, Geelong, Victoria, Bairnsdalian (Middle Miocene); three paralectotypes from same locality as lectotype, NMV P12229–31; paralectotype, NMV P12171, Bairnsdale Limestone (Bairnsdalian), Nicholson River, Bairnsdale, coll. A. W. Howitt; *Hinnites mulderi* Chapman, 1922, lectotype designated here (the sole remaining syntype), NMV P59353, Batesford Limestone (Batesfordian, Early Miocene), Batesford quarry, Batesford, Victoria; *Pecten deformis* Tate, 1887 (junior homonym of *Pecten deformis* Gabb, 1864) = *Hinnites tatei* Cossmann, 1907, lectotype designated here, Tate's (1887d) figured syntype, SAM T999A, 'upper beds' (Grange Burn Formation) at Muddy Creek, near Hamilton, western Victoria.

Other material examined. **Janjukian:** JAN JUC FORMATION: Jan Juc (2 specimens); WAURN PONDS LIMESTONE: Waurn ponds (1 specimen). **Longfordian:** MANNUM FORMATION: Murray cliffs between Wongulla and Mannum (1 specimen); FREESTONE COVE SANDSTONE: PL3028, Fossil Bluff (1 specimen); Table Cape (1 specimen) **Batesfordian:** BATESFORD LIMESTONE: PL3524, Batesford quarry (5 specimens); FYANSFORD FORMATION: PL3039, Curlewis (4 specimens). **Balcombian:** MUDDY CREEK FORMATION: PL3082, Clifton Bank (5 specimens); Muddy Creek (1 specimen); McDonalds Bank, below nodule bed (1 specimen); FYANSFORD FORMATION: Mornington (3 specimens); Flemington (1 specimen); PL3077, Altona Bay Coal Shaft (4 specimens); Hillberts Pit, Green Gully (2 specimens). **Bairnsdalian:** FYANSFORD FORMATION: PL3095, Western Beach, Corio Bay (25 specimens); Corio Bay (8 specimens); PL3101, Moorpanyl Park, North Shore (40 specimens); PL3072, Fyansford (2 specimens); PL3104, Manyung Rocks (3 specimens); PL3097, Murgheboluc 2B (1 specimen); Grices Creek (3 specimens); BAIRNSDALE LIMESTONE: PL3257, Wy Yung (6 specimens); PL3258, Dooley St lime pit (6 specimens); PL3276, Devils Backbone, Lochend (4 specimens); PL3256, Myrtle Point (1 specimen); PL3107, McCraes Quarry (47 specimens); PL3105, Hillside (2 specimens); PL3174, Nelson Brothers Lime Quarry (30 specimens); PL3175, Cameron's Arm, Lake Tyers (33 specimens); Bairnsdale (59 specimens); Nicholson River (7 specimens); Johnson's Farm, Hospital Creek (4 specimens); Tambo River cliff, Bumberrah 89P (9 specimens); Tambo River Cliff, 4 km north of Swan Reach (2 specimens); Princes Highway cutting, Toorloo Arm (12 specimens);


A
B
C
D
12231
E

Driers, Mitchell river (6 specimens); Cameron's Cliff, Cameron's Arm (2 specimens); Tambo River (1 specimen); Boggy Creek, Bairnsdale (2 specimens); PORT CAMPBELL LIMESTONE: Gravel Point, near Port Campbell (1 specimen); mouth of Sherbrooke River (1 specimen); top of London Bridge (2 specimens); WUK WUK MARL: PL3108, Driers (5 specimens); Rose Hill (1 specimen). **Mitchellian:** TAMBO RIVER FORMATION: PL3110, Swan Reach (8 specimens); Underwood's (1 specimen). **Cheltenhamian:** BLACK ROCK SANDSTONE: Cheltenham (1 specimen; mislocalised?).

Occurrence and time range. Janjukian to Mitchellian; unlikely to range as young as Cheltenhamian; a few specimens seen from Jan Juc Formation and Waurn Ponds Limestone, Otway Basin, a few from Mannum Formation, Murray Basin, and a few from Freestone Cove Sandstone near Wynyard, Tasmania; more than 90% of material is Bairnsdalian in age, from the Otway and Gippsland basins.

Remarks. The most obvious diagnostic character of *Austrohinnites corioensis* is the relatively few (12–14 on most specimens, max. *c*. 16) narrow, widely spaced, primary radial costae. Although secondary and tertiary costellae are formed on the '*Chlamys* stage' of most specimens by subdivision of the primary ones, by intercalation in the radial interspaces or by both means on one valve, the costellae remain relatively weak on almost all specimens and, even in those specimens where they develop into regularly fasciculate rib groups, with low secondary costellae on each side of the primary costae, intercostal spaces remain relatively wide and gently and evenly concave. Another character apparently diagnostic for *A. corioensis* is the relatively wide umbonal angle (*c*. 110°), particularly obvious on LVs and on the '*Chlamys* stage'. The remaining diagnostic character is the low, ventrally directed scales, forming short transverse ridges on the costal crests, developed on primary costae on the distal portion of the disc and auricles of the '*Chlamys* stage'. The scales develop over the distal quarter to tenth of the disc, leaving the early area of the disc of most specimens sculptured with low, smooth radial costae and wide areas of shagreen microsculpture in the radial interspaces, although secondary and tertiary costellae develop at up to the proximal third of the height in a few specimens.

Some specimens in the large, morphologically and sculpturally diverse Bairnsdale Limestone population remain in the regularly shaped '*Chlamys* stage' until a large size (up to 58 mm height observed; Fig. 10C) and in these costal interspaces become nearly flat, and secondary and tertiary costellae become numerous, complex, and evenly and weakly scaly. Most LVs of *A. corioensis* we have observed retain moderately regular, scaly primary costae that continue to subdivide fairly regularly across the disc of the cemented stage despite irregularity of shell growth in conformity with the substrate, and a coarse and somewhat irregular version of this sculpture remains on some RVs with a small attachment area. Other RVs, with a larger attachment area and greater distortion of sculpture through the development of irregular cementation lamellae, lack regular radial costae. Specimens we assign to *A. corioensis* from Tambo River Formation greensand at Swan Reach, PL3110, are the youngest specimens of *Austrohinnites* in Victoria, other than a single specimen (possibly mislocalised) from 'Cheltenham', ie., Beaumaris. From Swan Reach we know only eight *Chlamys*-like shells with wide umbonal angles, with flat intercostal spaces, with low scales on the primary costae, with irregularly subdivided and intercalated secondary and tertiary costellae, and with interspaces bearing coarse shagreen microsculpture; the largest (Fig. 10A) is 63 mm high. These specimens agree in all characters with the '*Chlamys* stage' of *A. corioensis*, and evidently represent a non-breeding population recruited from a nearby population cemented to a hard substrate.

Specimens from the Batesford lime quarry, PL3524, include the type material of '*Hinnites*' *mulderi* Chapman (1922: 5). The specimen figured by Chapman (1922) is not now present in Museum Victoria and apparently is lost, but one of Chapman's syntypes, labelled 'Batesford, pres. J. Mulder' remains in Museum Victoria (Fig. 8B) and is here designated the lectotype of *Hinnites mulderi* Chapman, 1922. This specimen and the few collected subsequently from the same locality are abraded, so the hinnitoid stage, in particular, has weak sculpture remaining, but the '*Chlamys* stage' has costae, costellae and scales indentical to those of *A. corioensis*. We are satisfied that these are merely abraded specimens of *A. corioensis*.

Fig. 9. *Austrohinnites corioensis* (McCoy), all at natural size. A, lectotype (designated here) of *Pecten deformis* Tate, = *Hinnites tatei* Cossmann, LV, SAM T999A, 'upper beds at Muddy Creek', Victoria, ie., reworked into Grange Burn Formation (Kalimnan) from underlying Muddy Creek Formation (Balcombian). B–E, *Hinnites corioensis* McCoy, all from Corio Bay, Geelong (Bairnsdalian): B, paralectotype, RV, P12231; C, paralectotype, LV, P12230; D, E, lectotype (designated here), LV, P12232, interior (uncoated) and exterior.

A
B
C
D
E

The lectotype of '*Hinnites*' *tatei* Cossmann, 1907 (= figured syntype of *Pecten deformis* Tate, 1887, a junior homonym of *P. deformis* Gabb, 1864) (Fig. 9A) is a severely abraded LV from the 'upper beds' (Grange Burn Formation) at McDonald's Bank, Muddy Creek, near Hamilton, western Victoria (Kalimnan, Early Pliocene). However, like many other abraded specimens from the Grange Burn Formation, there is no doubt that this shell has been reworked from the underlying Muddy Creek Formation (Balcombian, Middle Miocene). The specimen has moderately wide, gently concave intercostal spaces, and has costal subdivision and intercalation as in *A. corioensis*, but lacks scales. There is no doubt that this is merely a small specimen of *A. corioensis* with its scaly sculpture abraded off.

Austrohinnites polyaktinos (Ludbrook, 1955)

Figs 8F–H, 11A–H

Chlamys peroni; Woods, 1931: 150 (not *Pecten peroni* Tate, 1886; *fide* Ludbrook, 1955).

Chlamys (Chlamys) polyaktinos Ludbrook, 1955: 30, pl. 4, fig. 16.

Hinnites corioensis; Ludbrook, 1955: 34 (not *H. corioensis* McCoy, 1879).

Hinnites tatei; Ludbrook, 1973: 255, pl. 27, fig. 78 (not *H. tatei* Cossmann, 1907).

Description. Very similar to *A. corioensis* in most characters, differing in its smaller adult size, not exceeding *c.* 80 mm in height (compared with up to *c.* 120 mm in *A. corioensis*), its umbonal angle of *c.* 95° rather than *c.* 110°, its more strongly prosocline '*Chlamys* stage', its much more closely and frequently subdivided and intercalated costae on the '*Chlamys* stage' but markedly weaker sculpture on the ostreoid stage, reduced to *c.* 30–40 low, widely spaced, smooth costae; and the correspondingly much more obvious and dramatic, rapid change in sculpture between the '*Chlamys*' and ostreoid stages.

Dimensions.

Holotype of *Chlamys polyaktinos*:	H 23.5	L 22.0	RV
Adult, AK61732, Abattoirs Bore	62.2	58.5	LV
P302060, Bookpurnong Fm	68.4	64.6	RV
P302061, Bookpurnong Fm	60.0	60.7	LV

Type material. Holotype of *Chlamys polyaktinos* Ludbrook, SAM F15120, Abattoirs Bore, Adelaide, lower Dry Creek Sands, Bairnsdalian, Middle Miocene. Ludbrook (1955: 30) stated the type material as 'Holotype and 16 paratypes, Abattoirs Bore (single valves). One valve Hindmarsh Bore, two fragments Tennant's bore.'

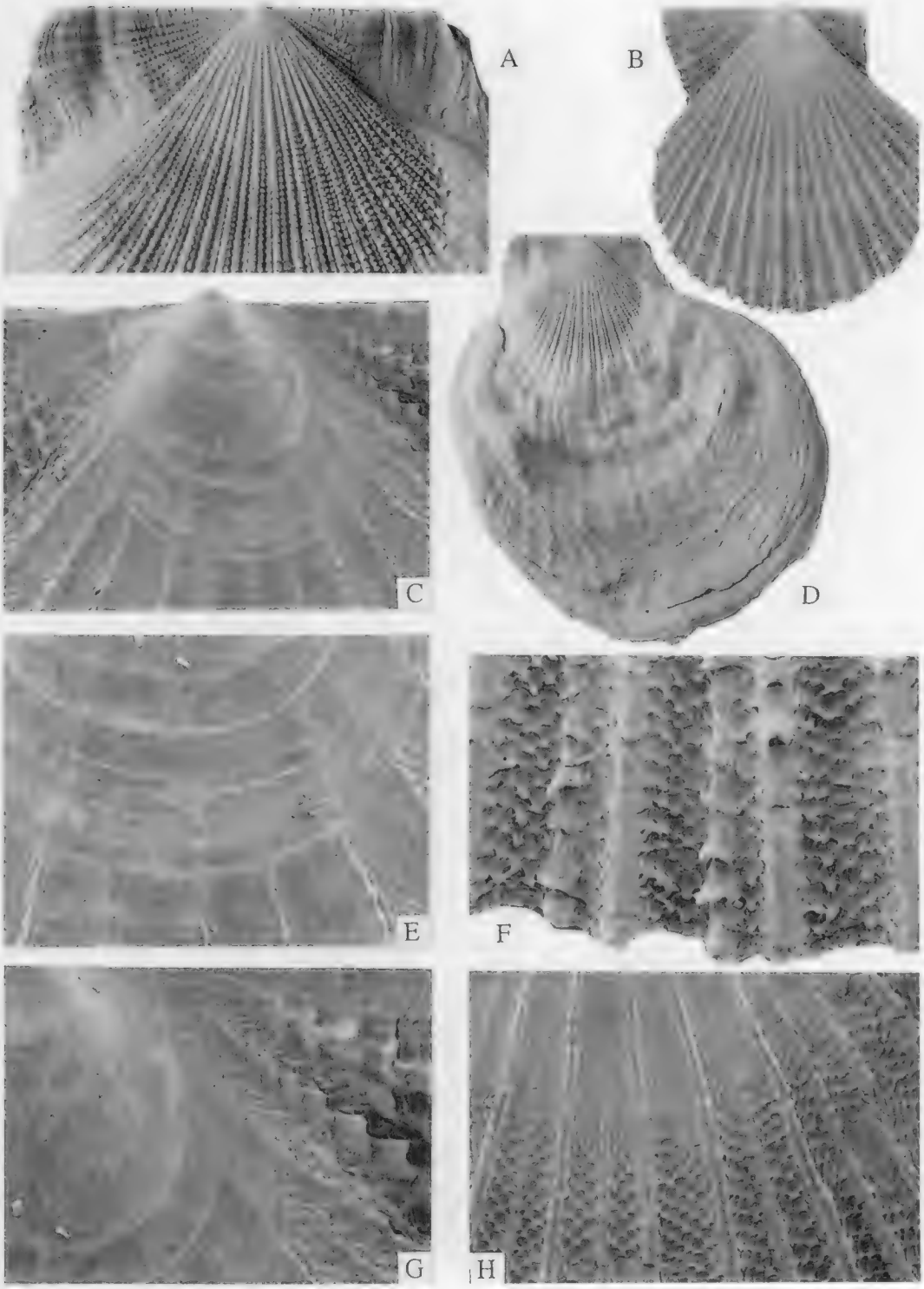
Other material examined. **Bairnsdalian:** BOOKPURNONG FORMATION: PL3133, Wookool bend (179 specimens); DRY CREEK SANDS: PL3598, Bore 593, Waterloo Corner, South Australia (45 specimens); PL3299, Abattoirs Bore (45 specimens); PL3596, house bore, Angas home (179 specimens).

Occurrence and time range. Abundant both in Dry Creek Sands in bores near Adelaide, St Vincent Basin, and Bookpurnong Formation near Loxton, Murray Basin; at both localities it is probably Bairnsdalian in age.

Remarks. Ludbrook (1955, 1973) evidently was confused about the identity of specimens from Dry Creek Sands, as she identified juvenile, '*Chlamys* stage' specimens and adults as different taxa in 1955, and in 1973 identified the same species, from Bookpurnong Formation, as *H. tatei* Cossmann, not recognising that the abundant juveniles in bores around Adelaide are conspecific with the abundant adults from Bookpurnong Formation. Dry Creek Sands samples not seen by Ludbrook include several showing the beginning of the irregularly growing stage, and at least one large, complete LV (Fig. 11D) closely comparable with Bookpurnong specimens (Fig. 8G, H). The abundant specimens from Bookpurnong Formation have very irregularly shaped adult stages, but the '*Chlamys* stage' agrees in all details with specimens from Dry Creek Sands.

Most diagnostic characters are stated above. Apart from the obvious differences from *A. corioensis* in size and closeness of sculpture, other significant differences are the radial interspaces being conspicuously narrower than in *A. corioensis*, the longer, more numerous, more prominent and more nearly semitubular costal scales than those of *A. corioensis*, and the obvious, rapid fading out of the scales and the more minor costae early on the irregularly growing stage. Coarse shagreen microsculpture is present in all radial interspaces on the '*Chlamys* stage'. The resulting ostreoid stage

Fig. 10. Austrohinnites corioensis (McCoy), all (other than B) at natural size. A, B, '*Chlamys stage*' LV, P300006, Tambo River Formation (Mitchellian), PL3110, Swan Reach, near Lakes Entrance, Victoria, natural size, and sculpture of ventral margin enlarged, × 3. C, P302063, incomplete RV with unusually large '*Chlamys stage*', Bairnsdale Limestone (Bairnsdalian), McCraes quarry, Toorloo Arm, Lake Tyers, Victoria. D, figured paralectotype of *Hinnites corioensis* McCoy, P12171, Bairnsdale Limestone (Bairnsdalian), Nicholson River, Gippsland. E, paralectotype of *Hinnites corioensis*, P12229, Corio Bay, Geelong (Bairnsdalian).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H

resembles those of the New Zealand Miocene species *A. marwicki* and *A. trailli* in its relatively subdued radial sculpture, but the more finely and closely costate and much more obviously scaly '*Chlamys* stage' distinguishes *A. polyaktinos* readily from all other known species of *Austrohinnites*.

Genus ***Dichotochlamys*** gen. nov.

Type species. *Pecten dichotomalis* Tate, 1886, Miocene, Port Phillip Basin, Victoria.

Diagnosis. Chlamydini with RV significantly more inflated than LV; with a moderately wide umbonal angle, length approximately equal to or a little greater than height; retaining a deep byssal notch, long RV anterior auricle and functional ctenolium in adults; with relatively large posterior auricles with a vertical, nearly straight posterior margin and few radial costae; with an almost smooth LV preradial dissoconch, bearing only low commarginal ridges; with weak antimarginal ridgelets developing at the same time as radial costae, strengthening down the disc to form consistent, complex ridgelets on crests of radial costae and intersecting with commarginal ridges to form characteristic frilled, prominent, moderately closely spaced commarginal lamellae; with frequently and closely subdivided and intercalated, numerous, narrow, closely spaced radial costae grouped into low indistinct plicae, initially 5 plicae on LV and 6 on RV, but subdividing at a variable size into more numerous plicae, plicae of all specimens subdividing at least weakly over outer disc of large shells, doubling in number early on disc on many specimens; with costal sculpture of many close, moderately long, narrow, semitubular, ventrally directed spines over outer quarter to half of disc; and with several large, narrow, dorsally directed spines along dorsal margins of RV auricles.

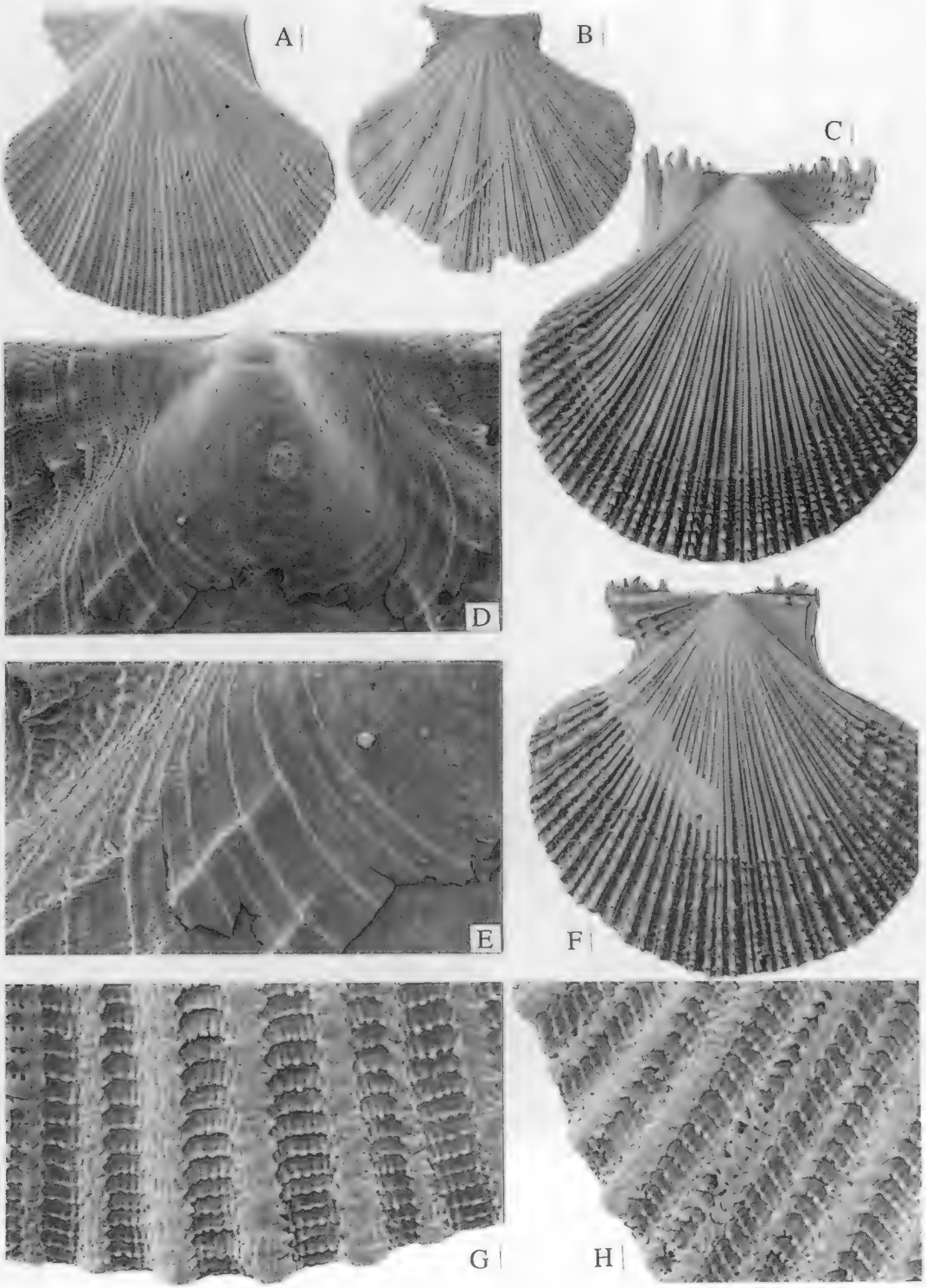
Remarks. *Dichotochlamys* gen. nov. is similar to *Talochlamys* (particularly the Miocene *T. keiloriana*) in many characters, and seems likely to be descended from a *Talochlamys* stock. The peculiarly fluted commarginal lamellae seen in *Dichotochlamys* are found also in some species of *Talochlamys*, and seem likely to be a character expressing a close phylogenetic relationship. *Dichotochlamys* differs from *Talochlamys* in its much narrower costae that are much more finely subdivided and intercalated in a regular series of three stages of subdivision down the shell of most large specimens, to produce a much greater number of costae on the outer part of the disc, in having long, prominent dorsal spines, and in being plicate. Also, the two valves are about equally inflated or, if anything, the LV is slightly more inflated than the RV in most species of *Talochlamys* [although some specimens of *T. dichroa* (Suter) have the RV more inflated than the LV], whereas in *Dicohotochlamys* the LV is almost flat and the RV is significantly more inflated than the LV.

Dichotochlamys dichotomalis has a superficial resemblance to species of *Mesopeplum* (Palliolini), as it shares with that genus the presence of plicae and the LV being less inflated than the RV. However, *Dichotochlamys* differs from Palliolini in lacking internal rib carinae and in retaining antimarginal ridgelets across the whole disc. The plicae are also less prominent than those of *Mesopeplum*, and are interpreted as independently evolved in this genus of Chlamydini (as they have also in many other genera of Chlamydini, such as *Equichlamys*, *Notochlamys* and *Semipallium*, among Australian genera). The combination of radial plicae and fine antimarginal ridgelets makes this genus and species immediately recognisable among Australian scallops.

At present, we include only the Australian Miocene type species in the genus. It is possible, though, that the two unnamed New Zealand species referred to *Notochlamys* by Beu & Maxwell (1990: 131, including pl. 9g) belong in *Dichotochlamys*, as they have relatively weak plicae, and re-examination shows that they lack true shagreen microsculpture, but have the same type of frilled, commarginal lamellae as *Dichotochlamys* and *Talochlamys*. They are of Early Oligocene and Middle Miocene age.

Etymology. The generic name (*dichotomalis* + *Chlamys*) reflects that of the type species, and refers to the series of dichotomous rib subdivisions that take place during ontogeny in most specimens of this species. Gender feminine.

Fig. 11. *Austrohinnites polyaktinos* (Ludbrook), lower Dry Creek Sands (Bairnsdalian), St Vincent Basin, South Australia. A, D, adult LV, AK 61732, Abattoirs Bore, Adelaide, ex Finlay Coll., '*Chlamys stage*' enlarged, × 3 (A) and whole shell at natural size (D). B, C, E–H, P300415, PL3596, Angas House bore, Salisbury, South Australia, SEMs of juvenile: B, whole shell, × 5; enlargements of sculpture of LV preradial dissoconch (slightly abraded); C × 16, E × 32 and G × 32; F, ventral margin, showing subdividing costae and shagreen, × 30; H, mid-disc shortly after costal inception, showing shagreen, × 32.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B
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H

Dichotochlamys dichotomalis (Tate, 1886)

Fig. 12A–H

Pecten dichotomalis Tate, 1886: 106, pl. 9, fig. 3a–c.

Description. Moderate-sized (25–35 mm high); umbonal angle moderately wide (105–110°); weakly inflated, RV more inflated than LV, which is nearly flat in many specimens; with five low, wide, indistinct plicae, each plica becoming rather evenly subdivided into two over distal half of most large specimens. Exterior sculpture of numerous narrow radial costae, *c.* 10 low, widely spaced primary ones on proximal disc, increasing irregularly by subdivision of primary costae and intercalation in centre of interspaces across disc, most large specimens passing through regular zones of relatively simple, superficially smooth costae with minutely frilled commarginal lamellae in interspaces (occupying *c.* proximal half of disc), similar median zone with simple costae and high, narrow, semitubular, ventrally cupped and directed spines on costal crests, and outer zone (occupying distal quarter to third of disc) of much more complexly and finely subdivided, consistently finely spinose costae, with many costae arranged in fasciculate groups. Anterior auricles long and narrow, in RV with deep, narrow byssal notch in adults, on both valves with 3–4 narrow, widely spaced radial costae, bearing low scales on RV and semitubular spines on LV; posterior auricles moderately large, tall, without prominent sculpture or with 1 or 2 narrow, prominent radial costae, posterior margins weakly concave in outline; dorsal margins of RV auricles very prominently spinose, spines tall and narrow, convex and shallowly cupped towards anterior on anterior auricle and towards posterior on posterior auricle.

Dimensions.

Lectotype, SAM T940A	H 19.9	L 21.3	RV
WAM 61.188, Balcombe Bay	24.9	25.1	RV
IGNS WM11420A, Muddy Creek	28.9	29.8	LV

Type material. Lectotype, designated here, of *Pecten dichotomalis* Tate, 1886 (Tate's figured syntype), SAM T940A, an incomplete RV with anterior auricle broken off, from 'Schnapper Point', ie., PL 3078, Fossil Beach, Balcombe Bay, 3 km south of Mornington, near Melbourne, Fyansford Formation, Balcombian. A LV (of the lectotype, or a paralectotype?—unclear) is glued to the same block as the lectotype by its exterior (SAM T940B).

Other material examined. **Balcombian:** FYANSFORD FORMATION: PL3078, Fossil Beach, Mornington (85 specimens); Mornington (7 specimens); MUDDY CREEK FORMATION: IGNS WM11420A, Muddy Creek, near Hamilton (1 specimen). **Bairnsdalian?:** FYANSFORD FORMATION: Grices Creek (1 specimen).

Occurrence and time range. Balcombian and probably Bairnsdalian; we have seen *D. dichotomalis* only from Fyansford Formation in the Port Phillip Basin; also one specimen from Muddy Creek Formation in the Otway Basin.

Remarks. In *Dichotochlamys dichotomalis*, increase in numbers of costae is mainly by subdivision on the RV and by almost equal numbers of subdivisions and intercalations on the LV; LV major costae, on the crests of plicae, tend to increase by subdivision, whereas costellae are intercalated in interspaces between the plicae. The minutely frilled commarginal lamellae are consistently prominent across the entire disc of most specimens, but become lower and less obvious at the point where the long, prominent, semitubular spines commence on many specimens; this point varies greatly in distance from the umbo from specimen to specimen. The two New Zealand species tentatively referred to *Dichotochlamys* have more numerous, more prominent and narrower plicae and fewer, coarser radial costae than *D. dichotomalis*.

Genus ***Equichlamys*** Iredale, 1929

Equichlamys Iredale, 1929a: 162.

Type species (by original designation, Iredale 1929a: 188). *Pecten bifrons* Lamarck, 1819, Late Pliocene to Recent, southern Australia.

Remarks. Equichlamys bifrons (Lamarck), the sole Australian species referred to the genus, is a highly distinctive and unusual pectinid. It combines the characters of nearly equal valve inflation, acline

Fig. 12. Dichotochlamys dichotomalis (Tate), type species of *Dichotochlamys* gen. nov., all from Fyansford Formation (Balcombian), Fossil Beach, Balcombe Bay, near Mornington. A, D, E, G, H, SEMs of juvenile LV, P300418: A, whole shell, × 4 (H 12.0 mm); D, E, sculpture of preradial dissoconch, enlarged (D × 24, E × 50); G, H, sculpture near mid-ventral and near anterior ventral margin, both enlarged, × 28. B, lectotype (designated here) of *Pecten dichotomalis* Tate, RV (anterior auricle incomplete), SAM T940A, × 2. C, F, P302095, RV and LV of an articulated pair, × 2.5.

or at most very weakly prosocline, equidimensional shape, a greatly reduced byssal notch, almost equal anterior and posterior auricles and lack of a ctenolium in adults, and prominent internal rib carinae (on the edges of the internal expression of the plicae, even when the plicae are extremely weak on the exterior) that are more usual in Aequipectinini and Palliolini, with the chlamydinine characters of coarse, uniform shagreen microsculpture over the entire exterior and a very weakly pitted, almost smooth LV preradial dissoconch microsculpture. The last two characters are shared with the Pliocene and younger species of *Notochlamys*, and it seems likely that *Equichlamys* is a genus of Chlamydini that has evolved internal rib carinae independently of other pectinids. *E. bifrons* also has a distinctive hinge, with prominent resilial and dorsal teeth.

Young specimens of *Equichlamys bifrons*, in the range of *c.* 10–30 mm high, are difficult to separate from *Notochlamys*. The problem is particularly obvious with the Roe Calcarenite pectinids, where juvenile *E. bifrons* are difficult to separate from *Notochlamys kendricki* sp. nov. The most fundamental character separating the two genera at this size is the size and shape of the RV anterior auricles; in all *Notochlamys* specimens they are much longer than the posterior ones and separated from the disc by a deep byssal notch, with a functional ctenolium, in even the largest adults, whereas in even the smallest juvenile *E. bifrons* the auricles are more nearly equilateral and the byssal notch reduced in size. The other useful character is the number of plicae; *Notochlamys* has only 5 in specimens with a narrow umbonal angle and up to 7 in wider specimens, whereas there are 7 or more on all *E. bifrons* and most specimens have 9–11 plicae. The number of plicae was of some help when sorting the Roe Calcarenite scallops, as all specimens of the endemic *N. kendricki* have 7 plicae. Another helpful distinguishing character is the umbonal angle, which is wide (*c.* 100–110°) in juvenile *E. bifrons*, but obviously narrower (*c.* 90–95°) in *N. kendricki*. Although the internal rib carinae are much more prominent and occupy much more of the shell height in adult *E. bifrons* than in adult *N. hexactes*, the relatively late development of the carinae in the much larger *E. bifrons* means that this character is of little help for distinguishing adult *Notochlamys* from small *E. bifrons*.

An important generic character is the coarse and unusually persistent shagreen microsculpture, which on unabraded specimens covers the entire surface, including costal and plical crests, of even the largest adults—and this is a rather large chlamydinine, reaching *c.* 120 mm high. The shagreen of unabraded specimens has laterally spreading outer lamellae, parallel to the true disc surface, meeting over the cellular lattice to form a complete, almost smooth secondary surface, but in many specimens the outer flat surface is abraded away, leaving only the bases of the lattice ridges forming a regular, even pattern of diamond-shaped lozenges.

Waller (1991: 31) pointed out that the Argentinian Miocene fossil *Pecten centralis* Sowerby, 1846 shares with *Equichlamys* the phylogenetically important characters of large size, greatly reduced byssal notch and subequal, almost square auricles, and persistent, coarse shagreen microsculpture over the entire exterior, and would make a feasible ancestor for *E. bifrons*. Certainly, *E. bifrons* appeared abruptly in southern Australia late in Pliocene time, with no obvious ancestors in Australia or New Zealand, giving every appearance of having arrived from elsewhere as planktonic larvae. Examination of a range of material of the *Pecten centralis* species group, collected in Argentina and brought to New Zealand by Dr Michael Griffin (La Plata Museum of Natural History, Argentina) showed that: (a) the species group is limited to Monte León Formation and the laterally equivalent Chenque Formation, of Late Oligocene or, more probably, Early Miocene age; and (b) the forms in Monte León Formation and Chenque Formation are highly variable, particularly in the number and prominence of radial costae and the prominence of the plicae. It appears very likely that, as with *E. bifrons*, the range of variation is so great that all the later-named 'species' fall within the range of variation of a single species: *P. centralis*. This species differs from *E. bifrons* in its much larger size (up to at least 200 mm high), the more strongly discrepant valve inflation—the RV is only moderately inflated and the LV a little more so in *E. bifrons*, whereas the LV is greatly inflated and the RV almost flat or even, in a few specimens, slightly concave in *P. centralis*—and in lacking all sign of internal rib carinae. The plicae vary greatly in prominence independently of the radial costae also, as in *E. bifrons*, although the costae tend to be more prominent in weakly plicate shells and less prominent in strongly plicate shells, again as in *E. bifrons*. The only phylogenetically significant character by which '*Pecten*' *centralis* differs from *E. bifrons* is the lack of internal rib carinae, and this could well be an individual character that has evolved only in *E. bifrons*. It seems feasible that *Pecten centralis* was the immediate ancestor of *E. bifrons*, and it appears reasonable to refer that

species, also, to *Equichlamys*. The one *Equichlamys* form we (including Dr Griffin) have observed in Argentinean faunas that appears to be distinct from *E. centralis* is an apparently unnamed species in the 'Juliense' [ie., traditionally referred to San Julian Formation; but actually referable to Chenque Formation] at Estancia La Central, southeast of Comodoro Rivadavia and west of Cabo Tres Puntas. During fieldwork at this locality in early 1998, Dr Griffin and AGB collected common specimens of a species that is more equivalve than *E. centralis* (both valves are convex) and reaches only about 130 mm in height, rather than *c.* 200 mm. This species, also, seems to lack the internal rib carinae of *E. bifrons*, but otherwise is much more similar to *E. bifrons* than is *E. centralis*.

However, the question of origins is merely transferred one step further back by the inclusion of *E. centralis* and the unnamed species in *Equichlamys*. *Equichlamys* appeared in Argentina in Monte León and Chenque Formations just as abruptly as *E. bifrons* appeared in southern Australia in Roe Calcarenite, and *E. centralis* and the unnamed species are limited to Monte León and Chenque Formations, without other phylogenetically close relatives in the earlier or later Cenozoic faunas of South America. The one possible slightly earlier, phylogenetically related taxon we are aware of in the Southern Hemisphere is *Athlopecten athleta* (Zittel), Late Oligocene–Early Miocene (Duntroonian–Waitakian), New Zealand. *A. athleta* shares with *Equichlamys centralis* the large size (reaching *c.* 200 mm high), the general shape and sculpture, with numerous coarse radial costae (or narrow plicae) but no sign of internal rib carinae, the LV a little more inflated than the RV as in *E. bifrons*, and the persistence of shagreen microsculpture across the disc of some rare unabraded shells. However, *A. athleta* differs from *Equichlamys* in having huge, wide, ventrally directed scales on costal crests, particularly on the narrower costae on the anterior and posterior disc flanks, in bearing prominent, thin, widely spaced commarginal lamellae over most of the disc and auricles of unabraded specimens and, most fundamentally, in retaining a much longer RV anterior auricle, a very deep byssal notch and a functional ctenolium at a much larger size than in either *E. centralis* or *E. bifrons*. This species therefore makes a plausible close relative of *Equichlamys*, but is in our perception distinct at the generic level.

Once again, though, the suggestion of *Athlopecten athleta* as a plausible ancestor of *Equichlamys* merely offsets the question of origins by another step. *A. athleta* appears just as abruptly and mysteriously in New Zealand Late Oligocene rocks as *Equichlamys* does in Argentina and later in southern Australia. It must be concluded that these large, plicate, shagreen-bearing scallops with nearly square auricles appeared repeatedly in the Southern Hemisphere fossil record from some outside area where they were continuing to evolve. Judging from the history of migration of tonnoidean gastropods (Beu 1976) and of *Pecten* (Fleming 1957) to the Southern Ocean later in Cenozoic time, a large, shagreen-bearing chlamydinine scallop in the Northern Hemisphere, such as *Patinopecten* Dall, 1898 or a related North Pacific genus, is likely to have given rise to these southern taxa.

***Equichlamys bifron*s** (Lamarck, 1819)

Figs 13A–H, 14A–F

Pecten bifrons Lamarck, 1819: 164; Deshayes, 1836: 131; Delessert, 1841, pl. 15, fig. 5a–c; Sowerby, 1842, pl. 1, figs 9, 10; Chenu, 1843: 3, pl. 22, fig. 3; Reeve, 1852: pl. 12, fig. 45; Chenu, 1862: 184, figs 925, 926; Tenison Woods, 1878: 56; Tate, 1887c: 108; Tate & May, 1901: 440; Chapman, 1920: 229; Dijkstra, 1995: 472, pl. 2, figs 4, 5; pl. 3, figs 6, 7.

Pecten subbifrons Tate, 1882: 44; Tate, 1886: 104, pl. 3, fig. 2.

Pecten consobrinus Tate, 1886: 104, pl. 3, fig. 6; Tate & Dennant, 1893: 224; Harris, 1897: 317; Tate, 1899: 269.

Pecten palmipes Tate, 1886: 105, pl. 5, fig. 4; pl. 7, fig. 4a, b; Harris, 1897: 318.

Chlamys bifrons; Pritchard & Gatliff, 1904: 263; Hedley, 1918: M9; May, 1921: 10; May: 1923, pl. 3, fig. 6; Coleman, 1975: 273, fig. 626.

Equichlamys bifrons; Iredale, 1929a: 162; Cotton, 1957: 127; Cotton, 1961: 97, fig. 82; Macpherson & Gabriel, 1962: 306, fig. 348; Waller, 1991: 30, pl. 3, figs 9, 10; Rombouts, 1991: 38, pl. 14, fig. 3a; Lamprell & Whitehead, 1992: pl. 10, fig. 60.

Equichlamys consobrina; Cotton, 1947: 654 (list).

Chlamys (Equichlamys) consobrina; Ludbrook, 1955: 31; Ludbrook, 1959: 225, pl. 1, fig. 2.

Chlamys (Equichlamys) palmipes; Ludbrook, 1959: 225, pl. 1, figs 3–6.

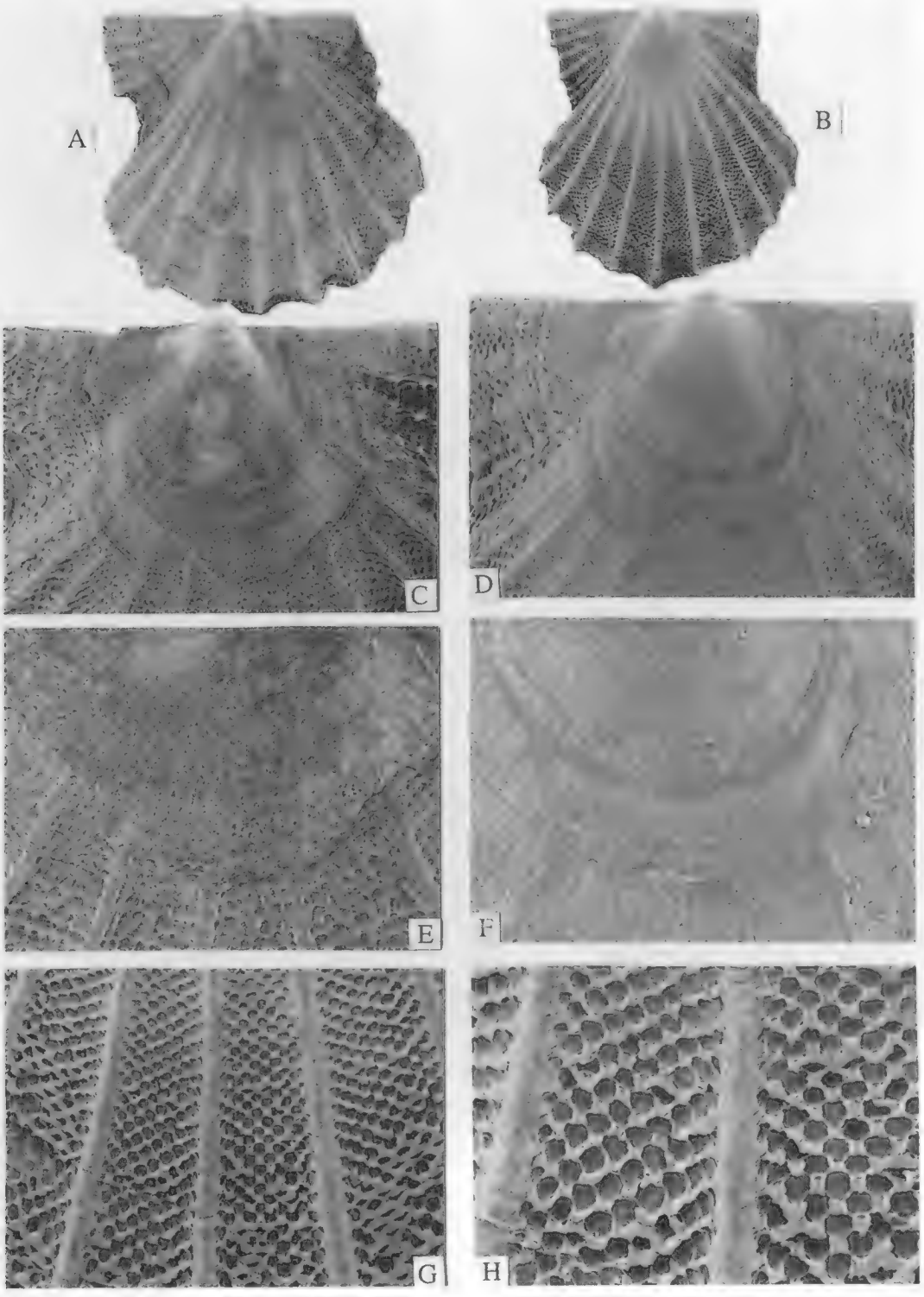
Chlamys (Equichlamys) subbifrons; Ludbrook, 1959: 224, pl. 1, fig. 1.

Chlamys (Equichlamys) bifrons palmipes; Ludbrook, 1978: 46, pl. 2, fig. 5.

Chlamys (Equichlamys) bifrons subbifrons; Ludbrook, 1978: 47, pl. 2, figs 6, 7; Ludbrook, 1983: 47; Ludbrook, 1984: 240.

Chlamys (Equichlamys) bifrons; Ludbrook, 1984: 160, 296, pl. 8f, fig. 38a, b.

Description. Large (to 120 mm high, but not commonly exceeding 100 mm high), acline to weakly prosocline, the two valves about evenly inflated or


A
B
C
D
E
F
G
H

RV slightly more inflated than LV, with moderately wide umbonal angle (100–115°); most prominent sculpture of 7–11 radial plicae (8–10 on most specimens), prominence varying greatly, from scarcely detectable, with wide, shallowly concave interspaces, to extremely prominent, with vertical sides, weakly convex crests and deep, narrow interspaces. Exterior surface sculptured with very numerous low, narrow, irregularly intercalated and subdivided radial costae, varying from very weak and widely spaced to moderately prominent and closely spaced; variation in prominence independent of that of plicae, although many weakly plicate specimens have prominent costae and many coarsely plicate specimens have very weak costae. Auricles large, high, particularly prominent in juveniles, byssal notch of RV anterior auricle moderately shallow in juveniles and shallow in adults, anterior margin merely strongly sinuous; LV anterior auricle tall, with convex anterior margin; posterior auricles tall, posterior margins almost straight to weakly concave in outline, almost vertical to inclined moderately strongly towards anterior. Ctenolium present in small specimens, of quite robust, rounded teeth, remaining as a row of teeth in groove between auricle and disc for half valve height of large specimens, or a little over; ceasing abruptly. Exterior sculptured with prominent, coarse shagreen over all other sculpture on unabraded specimens. Interior with very prominent, narrow, well raised rib carinae over ventral half of disc, one pair corresponding to each external plica and 1–2 extra carinae near anterior and posterior ends. Hinge with prominent, wide dorsal and resilial teeth in RV and corresponding sockets in LV.

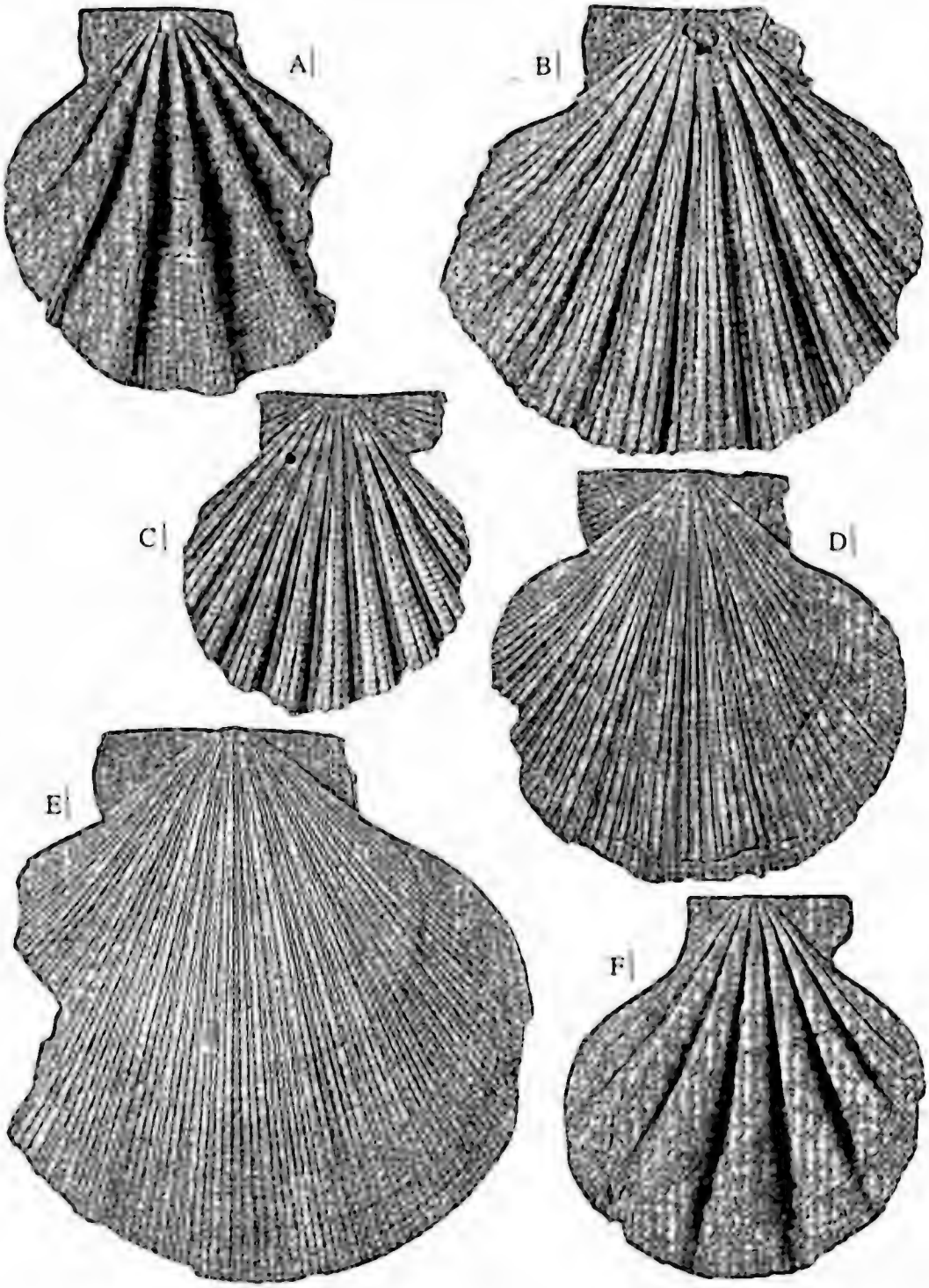
Dimensions.

Lectotype of *P. bifrons* (Dijkstra 1994: 472)	H 101	W 106	
Large paralectotype MHNG 1088/14/2	98.5	100.5	
Paralectotype, MHNG 1088/14/1	106	110	
Pecten palmipes Tate			
Lectotype, SAM T932A	57.1	53.6	RV
	58.5	50.1	LV
Pecten subbifrons Tate			
Lectotype, SAM T959A	31.1	27.6	RV
Paralectotype, SAM T959C	46.6	47.7	LV
Pecten consobrinus Tate			
Lectotype, SAM T937B	62.4	62.9	LV
Paralectotype, SAM T937A	84.3	79.9	LV
Highest seen, AMS C2417 Hobart, Tasmania	H 115.1	W 115.8	
Widest seen, AMS C92282 Tasmania	114.0	118.5	

Type material. Lectotype of *Pecten bifrons* Lamarck, 1819 (designated by Dijkstra 1995: 472, pl. 2, figs 4, 5; pl. 3, figs 6, 7): MNHN, Paris; 3 paralectotypes in MNHN; 2 paralectotypes in MHNG, 1088/14/1 and 1088/14/2, labelled 'les mers australes et de la Nouvelle Hollande. *Péron*', indicating that Lamarck's material was collected in southern Australia by Péron during the voyage of the '*Géographe*' and the '*Naturaliste*'. *Pecten subbifrons* Tate, 1882, lectotype designated by Ludbrook (1959: 224), Tate's (1886: pl. 3, fig. 2) figured specimen, SAM T959A, from 'Adelaide', ie., Hallett Cove Sandstone, Late Pliocene [Ludbrook (1959) stated that Tate's (1886) figured specimen was the holotype, but Tate (1886) did not select individual type specimens, and his type lots must be regarded as syntypes where he had more than one specimen; Ludbrook's statement that one specimen is the holotype constitutes designation of that specimen as the lectotype (ICZN Code, Article 74.6); this applies equally to *P. consobrinus* Tate]; 4 paralectotypes, SAM T959B–D, same data. *Pecten consobrinus* Tate, 1886, lectotype designated by Ludbrook's (1959: 225, 233) 'holotype' statement, Tate's (1886: pl. 3, fig. 6) figured syntype, SAM T937B, from 'oyster banks, Aldinga', ie., Hallett Cove Sandstone, Late Pliocene; paralectotype, SAM T937A, same data; 4 paralectotypes, SAM T968A–D, unfigured (T968A marked 'Hallett's Cove', others marked 'mouth of Onkaparinga River'), all appear to be from Port Willunga Formation (Oligocene) at mouth of Onkaparinga River, and are not conspecific with lectotype. *Pecten palmipes* Tate, 1886, lectotype designated by Ludbrook (1959: 225), SAM T932A, Tate's (1886: pl. 7, fig. 4a, b) figured syntype, from Edithburgh, South Australia, Hallett Cove Sandstone, Late Pliocene; paralectotype, SAM T932A, same data.

Other material examined. **Late Pliocene:** UPPER DRY CREEK SANDS: Grange Oil Well No. 1 (1 specimen); PL3611, Royal Adelaide Golf Course bore (1 specimen); HALLETT COVE SANDSTONE: PL3291, Giles Point (1 specimen); PL3599, Hallett Cove (1 specimen); PL3600, Blanche Point (7 specimens); Aldinga (51 specimens); Port Willunga (10 specimens); road to jetty, Port Willunga (2 specimens); PL3467, south of jetty, Port Willunga (4 specimens); Stansbury (1 specimen); WAM 79.1879, Port Willunga (3 specimens); AMS C133295, Aldinga (1 specimen); NORWEST BEND FORMATION: PL508, cutting, Jervois Punt (53 specimens); PL3179, Freds Landing (144 specimens); rear of picnic reserve, Jervois Punt (5 specimens); Moorlands, South Australia (6 specimens); ROE CALCARENITE: PL3167, 1.6 km N of Hampton Tower

Fig. 13. Equichlamys bifrons (Lamarck), type species of *Equichlamys* Iredale, 1929, SEMs of two Recent juvenile LVs, AMS C300340, 15 m, Tinderbox, Derwent Estuary, Tasmania. A, whole specimen, × 14. C, E, sculpture of preradial dissoconch (C × 37, E × 75). B, whole specimen, × 14. D, F–H, slightly weaker preradial dissoconch sculpture than in Fig. 13C, E, passing down disc into shagreen (D × 35, F × 70, G × 85, H × 170).


A
B
C
D
E
F

(129 specimens); PL3172, Hampton Tower (34 specimens); pit on Eyre Highway, 74 km W of Eucla Motel, Eucla 421 477 (7 specimens); pit 0.6 km N of Hampton Tower (2 specimens); WAM 61.35, 32 km E of Madura (1 specimen); WAM 67.750, 51 km E of Madura (1 specimen); WAM 69.462, Hampton Tower, Roe Plains (1 specimen; figured by Ludbrook 1978: pl. 2, fig. 7); WAM 69.661, 74 km W of Eucla Motel, Eyre Highway (1 specimen; figured by Ludbrook 1978: pl. 2, fig. 5); WAM 70.1087, pit 0.8 km N of Hampton Tower (2 specimens); WAM 70.2153, pit 51.5 km E of Madura (1 specimen; figured by Ludbrook 1978: pl. 2, fig. 6); WAM, pit 0.4 km N of Hampton Tower (4 specimens); WAM 81.1792, quarries beside road from Eyre Hwy to Hampton Tower (1 specimen); PL3166, 2.5 km N of Hampton Tower (6 specimens); PL3165, MRD quarry S of Madura Roadhouse (6 specimens); AMS C90093, excavation spoil, *c.* 3.2 km N of Hampton Tower, 51 km E of Madura (10 specimens); AMS C105250, Eyre Highway, 105 km E of Madura (1 specimen); 'OLDER' ASCOT FORMATION, PERTH BASIN: WAM 66.921, Gnagnara No. 5 bore (1 specimen); WAM 75.353, Pinjar No. 110 bore, NE side Lake Pinjar (3 specimens); WAM 86.585, Jupp's No. 1 bore, West Gingin (18 fragments); WERRIKOO LIMESTONE: Ponderosa Quarry (1 specimen); Limestone Creek (6 specimens); Glenelg River cliffs, allot. 3, Parish of Dartmoor (1 specimen). **Early Pleistocene:** MEMANA FORMATION: PL1207, 'Brunah' D, Memana (1 specimen); PL1216, 'Marapana' A, Memana (1 specimen); AMS C132198, N of Memana, Flinders Island, from dam spoil (1 specimen, with very prominent, vertical-sided plicae); 'YOUNGER' ASCOT FORMATION, PERTH BASIN: WAM 67.569, Adrian's Nursery bore, Jandakot (5 specimens); WAM 67.797, as above (1 specimen); WAM 70.1436, Poletti's bore, Semple Rd, Jandakot (1 specimen); WAM 70.1797, Poletti's bore, Jandakot (1 specimen); WAM 71.843, Pederson's bore, Russell Rd, Thompson Lake (5 specimens); WAM 72.953, Jandakot Cement Works bore, Parkes Rd, Yangebup (1 specimen); WAM 72.1072, as above (1 specimen); WAM 72.1252, as above (1 specimen); WAM 74.36, Paulik's bore, Jandakot (1 specimen); WAM 74.235, as above (1 specimen); WAM 74.614, as above (4 specimens); WAM 76.107, as above (1 specimen); WAM 77.994, Nu-Mix Concrete bore, Macglaglan St, Jandakot (2 specimens); WAM 77.1032, as above (3 specimens). (Younger fossils not listed.)

Occurrence and time range. The earliest record of *E. bifrons* is in Roe Calcarenite, in the Eucla Basin. As noted above under 'Biostratigraphy', this formation is Late Pliocene, younger than the Kalimnan upper Jemmys Point Formation of the Gippsland Basin and than Cameron Inlet Formation of Flinders Island, but older than Hallett Cove Sandstone of the St Vincent Basin, Norwest Bend Formation of the Murray Basin and the 'older' Ascot Formation of the Perth Basin, in which *E. bifrons* is common. *E. bifrons* is therefore of some utility in biostratigraphy, indicating Late Pliocene age and younger. At present, it ranges from Ceduna, South Australia, to southernmost New South Wales, including the whole of Tasmania; a single faded specimen in AMS from Sydney Harbour is likely to be a Pleistocene or Holocene fossil, as are most of the taxa reported from dredgings from the harbour floor by Iredale (1929b, 1931).

Remarks. The range of variation of *Equichlamys bifrons* has troubled paleontologists from Tate (1882) to Ludbrook (1984). Tate (1886), with little knowledge of the Recent population, assumed that the several forms present in young rocks around Adelaide were distinct species. However, not having the present knowledge of ages of Cenozoic rocks in South Australia, he also confused some older forms with *E. bifrons*, from the Oligocene Port Willunga Formation near the mouth of the Onkaparinga River, near Adelaide. His type material of *Pecten consobrinus* includes two strongly plicate and unusually strongly costate specimens of *E. bifrons* from Hallett Cove Sandstone (Pliocene) (Fig. 14B, C), and two specimens of *Notochlamys squamundata* sp. nov. (Fig. 15G, H), and two of a more *Chlamys*-like taxon from Onkaparinga. These latter four specimens differ from *E. bifrons* in their narrower umbonal angle, in two having narrower and more evenly rounded plicae whereas two have low costae without plicae, in their costal sculpture of low, closely spaced scales and, on the RV, a much larger anterior auricle and a deep byssal notch. However, Tate's confusion is understandable, as both the plicate specimens have 10 plicae (a similar number to that on many large *E. bifrons*, which have *c.* 7–11 plicae) and the LV bears persistent shagreen microsculpture in the intercostal spaces.

Fig. 14. Equichlamys bifrons (Lamarck), syntypes of synonyms named by Tate (1886), illustrating variation in costal and plical prominence; all from Hallett Cove Sandstone (Late Pliocene), South Australia. A, F, lectotype, designated by Ludbrook (1959) (Tate's figured syntype) of *Pecten palmipes* Tate, SAM T932A, LV and RV of one specimen, 'Edithburgh', at natural size. B, C, 2 of 5 syntypes of *Pecten subbifrons* Tate, 'Adelaide', enlarged, × 1.5: B, RV, paralectotype, SAM T959C; C, RV, lectotype, designated by Ludbrook (1959) (Tate's figured syntype), SAM T959A. D, E, *Pecten consobrinus* Tate, 'oyster banks, Aldinga Bay', at natural size: D, lectotype, designated by Ludbrook (1959) (Tate's figured syntype), LV, SAM T937B; E, paralectotype, LV, SAM T937A.

Cotton (1947) suggested that *Equichlamys subbifrons* and *E. palmipes* were probable synonyms of *E. consobrinus* (Tate) and Ludbrook (1978) reduced Tate's 'species' to 'subspecies' of *E. bifrons*, but this merely provides names for the more extreme variants within a single population. Comparison with the large collections available from commercial fisheries (NMV, AMS) showed that all these forms intergrade in the present-day fauna, and within a collection dredged from a single locality. The variation of the Pliocene population seems no different from that of the present-day one, and we regard Tate's names as synonyms of *E. bifrons*. The color, also, is variable within the present-day population. Whereas most specimens are pale purple or violet, particularly on the interior (the exterior is whitish to pale brown on some specimens with complete shagreen), about 10% of the population is pale orange.

Genus *Notochlamys* Cotton, 1930

Notochlamys Cotton, 1930: 233.

Type species (by original designation). *Chlamys anguinea* Finlay, 1927 (new name for *Pecten undulatus* Sowerby, 1842, *non* Nilsson, 1827) (= *Pecten hexactes* Lamarck, 1819), Recent, southern Australia.

Remarks. Specimens of *Notochlamys hexactes* (Lamarck) resemble small specimens of *Equichlamys bifrons* closely in shape and sculpture, both having conspicuous shagreen microsculpture and plicae that are variously developed, but are obvious on most specimens. They share, also, very weakly pitted LV preradial dissoconch microsculpture and very similar, moderately prominent resilial and dorsal hinge teeth. It is shown under *Equichlamys* that *Notochlamys* differs from *Equichlamys bifrons* in its much smaller adult size, in having much weaker internal rib carinae, and in retaining throughout life a byssally attached habit, and the consequent shell morphology with a long RV anterior auricle, a deep byssal notch and a functional ctenolium. Beu (1978) regarded *Notochlamys* as a synonym of *Mesopeplum* Iredale, 1929, but Waller (1991) pointed out that the characters separating these two genera include some of his newly indicated, phylogenetically useful characters, so their similarity is purely superficial, and they belong in different tribes. *Mesopeplum* lacks both shagreen and antimarginal microsculpture, its only disc microsculpture being widely spaced, commarginal lamellae (diagnostic, among other characters, of Tribe Palliolini), and differs further from *Notochlamys* in lacking a functional byssal notch and ctenolium in the adult [at least, in *M. fenestratum* (Hedley), the Australian Recent type species].

Evidence of a close phylogenitic relationship to *N. hexactes* by the Australian pre-Pliocene species is lacking because of the lack of preservation of critical characters. Nevertheless, they are evenly plicate (ie., with plicae and their interspaces evenly spaced and evenly rounded, so that an interspace is the mirror image of a plica in cross-section) and have shagreen microsculpture, so may be plausible ancestors for the Pliocene to Recent species, and if nothing else are much closer homeomorphs than is *E. bifrons*. The similarity of *N. hexactes* to *E. bifrons* is therefore viewed as yet another confusing convergence, rather than reflecting a close phylogenetic relationship.

Del Rio (1995) referred a new evenly plicate, shagreen-bearing chlamydinine species from the Early Miocene Chenque Formation (as used by Barreda 1996) of the Gulf of San Jorge, Argentina, to *Swiftopecten* Hertlein, 1936. The new species, *S. iheringii* del Rio, has a narrower umbonal angle than most *Notochlamys* species (although similar to that of some small specimens of the Pliocene *N. kendricki* sp. nov.) but resembles *Notochlamys* species in its five evenly rounded plicae, its shagreen microsculpture and its long anterior auricles. In shape and in the presence of growth ledges, *S. iheringii* resembles North Pacific species of *Swiftopecten* closely related to *S. swiftii* (Bernardi) (eg., MacNeil 1967: pl. 3; Waller 1991: pl. 2, figs 9, 10) more closely than it does *Notochlamys*. Nevertheless, the overall similarity of *S. iheringii* to *Notochlamys* species and the intermediate geographic position of *S. iheringii* raise the possibility of a closer phylogenetic relationship between *Notochlamys* and *Swiftopecten* than their present morphologies and distributions would seem to suggest. However, this relationship is unclear at present, and further similar, plicate, shagreen-bearing chlamydinines occur in other parts of the world, such as *Manupecten* and *Semipallium* (Waller 1991: 24–26) and the phylogeny of all these taxa, as suggested by Waller (1991), needs reconsideration in light of the earlier Australian records of *Notochlamys* reported here. As *Notochlamys* Cotton, 1930 is the earlier of the two possible synonyms *Notochlamys* and *Swiftopecten*, this question does not affect the generic identity of the Australian taxa.

Notochlamys*(?) *nanarupensis sp. nov.

Figs 15E, 16G, H

Description. Moderately large for genus (to *c*. 56 mm high), almost equidimensional, slightly prosocline, RV slightly more inflated than LV; umbonal angle *c*. 105°; initial umbonal angle moderately narrow, but dorsal margins strongly concave (curved outwards) to produce wider umbonal angle as shell grows; posterodorsal margin significantly longer than anterodorsal margin. Sculptured with 17–19 evenly rounded but low, relatively narrow, radial plicae (or relatively large, smooth, evenly rounded costae), weakly subdividing on some specimens, particularly near anterior and posterior ends of disc, where plicae are lower, narrower and more closely spaced than elsewhere; crossed only by very fine antimarginal ridgelets and weak commarginal growth ridges; one paratype bears obvious, fine shagreen microsculpture over antimarginal ridgelets in interplical spaces. Anterior auricles large, elongate; on RV with deep byssal notch and functional ctenolium (with *c*. 5 narrow, elongate teeth) and wide, deeply impressed byssal fasciole, bearing coarser commarginal growth ridges than remainder of shell; main auricle face above fasciole sculptured with 3–4 moderately high, narrow radial costae over lower half of main auricular surface only, costae crossed by even, regular, closely spaced, moderately high commarginal lamellae; on LV tall, with anterior margin very weakly sinuous and inclined strongly towards anterior, sculptured with 4–5 very weak, widely spaced radial costae but without commarginal lamellae. Posterior auricles very short, with posterior margin slightly concave and inclined strongly towards anterior, sculptured with only 1 or 2 very low, narrow radial costae on each valve margin. Dorsal margin of RV anterior auricle raised well above hinge line in irregular, weakly convex outline, weakly serrated by commarginal lamellae. Hinge of RV with low, narrow, resilial and dorsal teeth; LV hinge not seen. Interior of ventral margin smooth, without internal rib carinae.

Dimensions.

Holotype, WAM 69.235	H 56.0	L 54.7	LV
Paratype, WAM 69.234	55.7	55.9	RV
Paratype, WAM 75.27b	56.2	52.7	RV
Paratype, WAM 72.46d	43.7	42.6	RV
Paratype, WAM 94.712	52.9	53.6	RV

Type material. Holotype, WAM 69.235, Nanarup Limestone Member of Werillup Formation (Aldingan, Late Eocene), PL508, Nanarup Lime Quarry, near Albany, southern Western Australia, coll. O. Thorne, 10.iii.1969; paratype, WAM 69.234, all data as above; WAM 72.46a–e, 5 paratypes, data as above, coll. G. W. Kendrick, 25.i. 1972; paratype, WAM 94.712, data as above, coll. K. J. McNamara, 1990–1993.

Other material examined. **Aldingan:** NANARUP LIMESTONE: PL508, Nanarup Quarry (8 specimens); PALLINUP SILTSTONE: WAM 76.1234, small quarry by fence line, headwaters of Mungliginup Creek, near Esperance, WA, map ref. SI/51-6/564817 (partial mould, with similar costae to *N. nanarupensis*, and with fine shagreen all over; auricles missing and disc shape not determinable).

Occurrence and time range. Known with certainty only from the type locality (Late Eocene); an incomplete mould from Pallinup Siltstone (also Late Eocene) in southern Western Australia probably belongs here also.

Remarks. The new species is clearly a very aberrant member of *Notochlamys*, if referable there at all. One paratype (WAM 72.46d, a nearly complete RV; Fig. 15E) bears obvious, if fine, shagreen microsculpture in the interplical spaces, but the specimen is rather atypical of *N. nanarupensis*; it is a little more inflated than the other material, and the margins of the strongly rounded costae (or narrow plicae) are more sharply defined than in all other specimens. Nevertheless, with 18 narrow, strongly rounded, smooth plicae on an RV with the same shape of anterior auricle as the paratype WAM 69.234, it seems likely to be conspecific with the other material from the same locality. All the material is distinguished from the other species referred here to *Notochlamys* by its markedly narrower and more numerous plicae, by having only one order of radial sculpture, and by having a rather wider shape. In the absence of knowledge of the LV preradial dissoconch microsculpture (always impossible to see on material from limestone, and particularly difficult on Eocene material) the taxonomic position of this species will remain tentative, but it makes a plausible early, ancestral species of *Notochlamys*.

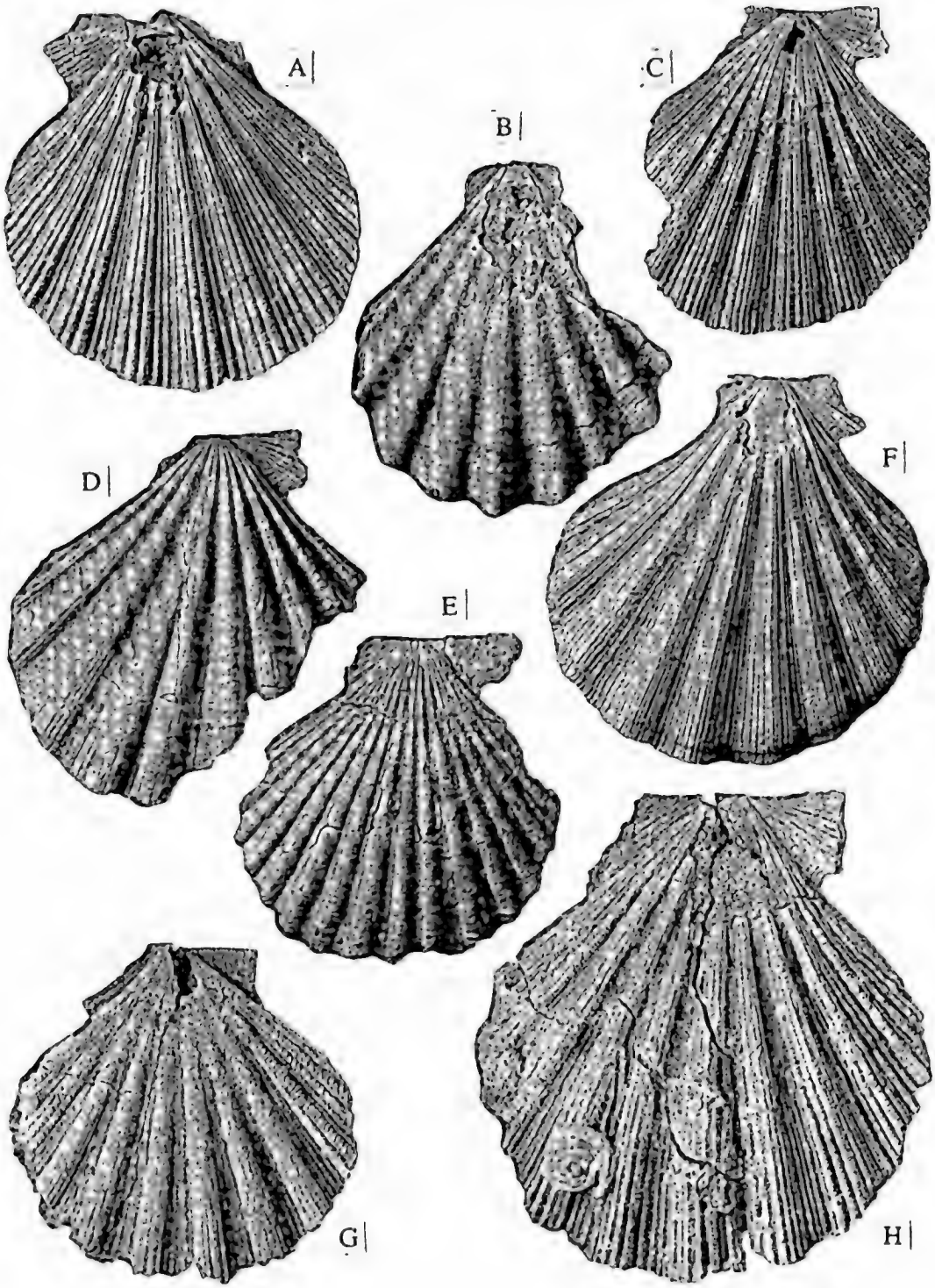
Etymology. The specific name ('from Nanarup' [Quarry]) refers to the type locality of the species.

Notochlamys*(?) *squamundata sp. nov.

Fig. 15A–D, F–H

?*Notochlamys antecedens*; Ludbrook, in Lowry 1970: fig. 2II, J (not *N. antecedens* Singleton, 1941 = *Semipallium foulcheri* Tenison Woods, 1867).

Description. Average-sized for genus (40–50 mm high), moderately inflated, inflation of RV about equal to LV; umbonal angle moderately narrow, 95–105°; with *c*. 10 evenly rounded plicae, apparently in most specimens consisting of an initial 5 plicae, each subdividing early on the disc;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acline to slightly prosocline. Radial costae low, fine, numerous, *c.* 7–10 on each plica on central area of disc, fewer on narrower, anterior and posterior plicae, 3–5 in interplical spaces; secondary and tertiary costellae subdivided and intercalated down disc to maintain costal proportions and spacing; all bearing obvious, low, closely spaced, ventrally directed scales over entire disc and auricles. Interplical spaces and, on some specimens, costal interspaces on and between plicae on distal area of disc bearing low, fine but obvious shagreen microsculpture, one specimen with shagreen raised into secondary shell surface over plicae on proximal two thirds of disc. Anterior auricles large, elongate, with deep byssal notch and functional ctenolium in RV, but slightly to severely incomplete in all available material; posterior auricles small, short, with weakly concave posterior margin. Hinge (visible only in paratype, RV, WAM 88.810c) with narrow but obvious resilial and dorsal teeth; interior of ventral margin without internal rib carinae.

Dimensions.

Holotype, P302636	H 49.1	L 48.9	RV
Paratype, SAM T968B paralectotype of *P. consobrinus*	43.8	41.8	RV
Paratype, SAM T968C paralectotype of *P. consobrinus*	37.0	33.8	LV
Paratype, WAM 88.810a Onkaparinga	38.8	36.1	LV

Type material. Holotype, NMV P302636, Port Willunga Formation (Janjukian), PL3293, quarry and cliffs north of jetty at Stansbury, Yorke Peninsula, South Australia, grid ref. Stansbury 554344, coll. T. A. Darragh, 29.iv. 1996; one paratype, NMV P302863, same data; two paratypes, SAM T968B, C, two of Tate's (1886) unfigured paralectotypes of *Pecten consobrinus* Tate, from 'mouth of Onkaparinga River', Port Willunga Formation, late Eocene (Aldingan), near Adelaide, South Australia; three paratypes, WAM 88.810a–c, Port Willunga Formation, (Willungan, Oligocene), 200 m south of Onkaparinga Trig., Onkaparinga, near Adelaide, South Australia, coll. K. J. McNamara, 23.iii.1986.

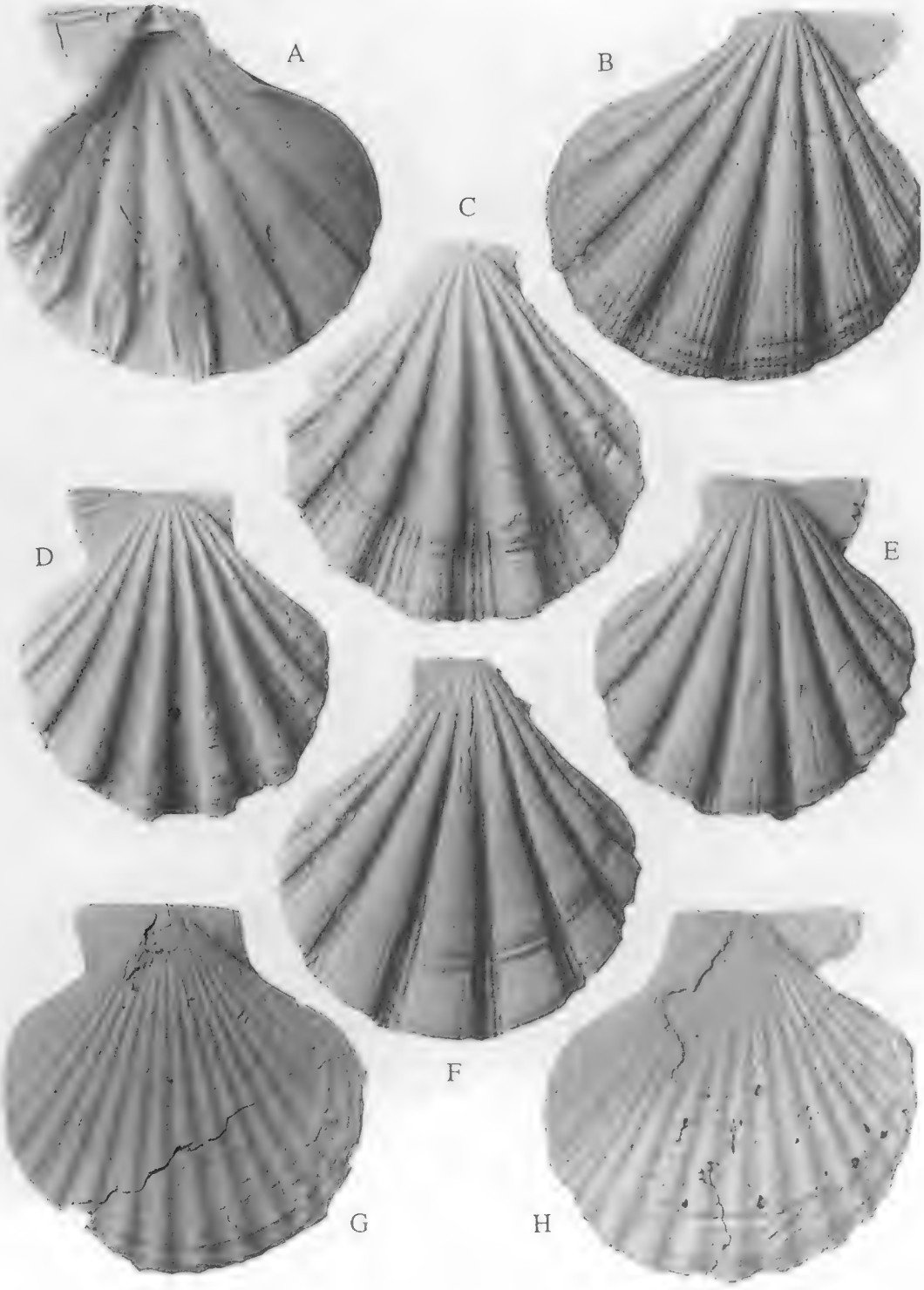
Other material examined. **Janjukian:** JAN JUC FORMATION: Bird Rock ledge, Torquay (1 specimen); PORT WILLUNGA FORMATION: PL3292, Wool Bay (1 specimen); PL3293, Stansbury (2 specimens). **Longfordian:** MELTON LIMESTONE: PL3295, Myponie Point (8 specimens); PL3296, Black Rock (11 specimens); fragmentary specimens from ABRAKURRIE LIMESTONE, Eucla Basin: WAM 65.646, Mullamullang Cave, near Madura, *c.* 1.6 km in from entrance, 100 m below surface (1 specimen); WAM 68.112, Mullamullang Cave, at bottom of entrance, not in situ (one RV); WAM 68.125, Mullamullang Cave (one fragment); WAM 68.320, Murra-el-elevan Cave (1 specimen).

Material illustrated by Ludbrook (in Lowry 1970: fig. 21I, J), under the name *Notochlamys antecedens* Singleton, from Abrakurrie Limestone at Murra-el-elevan Cave and Firestick Cave, Nullarbor Plain, seems likely to be based on further records of *N. squamundata*. However, we have not seen all the material (in GSWA) and it has some similarities to *Semipallium foulcheri*, so these records need confirmation.

Occurrence and time range. Aldingan(?) to Longfordian. Most material is from St Vincent Basin; fragmentary specimens from Abrakurrie Limestone in the Eucla Basin and one from Torquay, Port Phillip Basin, Victoria.

Remarks. Most of the material assigned to *Notochlamys squamundata* sp. nov. bears the distinctive character of finely but closely and obviously scaly radial costae, which distinguishes this species from all other species we assign to *Notochlamys*. However, one paratype, NMV P302863, from the same lot as the holotype, lacks radial costae altogether, and simply has smooth, evenly rounded plicae of high amplitude, evenly sculptured with fine shagreen all over. The one specimen from Jan Juc Formation at Torquay that we assign here is very similar to this smooth paratype, but develops weak radial costae around the ventral margin of the disc. Not a single one of the specimens assigned here, however, is well enough preserved for the LV preradial dissoconch sculpture to be visible, so the whole lot, including the type material, is assigned here purely on gross morphology. It appears reasonable, though, to assign this species to *Notochlamys*, and there is certainly no other genus known to us from Australia that would be

Fig. 15. A–D, F–H, *Notochlamys*(?) *squamundata* sp. nov., enlarged, × 1.5 (A, C), × 1.25 (B, D, F) and × 2.0 (G, H): A, paratype, LV, WAM 88.810a, Port Willunga Formation (Janjukian), 200 m S of Onkaparinga Trig station, South Australia; B, paratype, RV, P3026863, Port Willunga Formation (Janjukian), PL3293, 100–200 m N of jetty, Stansbury, South Australia; C, paratype, RV, WAM 88.810b, locality as Fig. 15A; D, paratype, RV, P302070, Jan Juc Formation (Janjukian), Bird Rock ledge, Torquay, Victoria; F, holotype, RV, P302636, locality as Fig. 15B; G, H, unfigured paralectotypes of *Pecten consobrinus* Tate, 'mouth of Onkaparinga' [River], South Australia, 2 of 4 on tablet; G, LV, SAM T968D; H, RV, SAM T968C. E, *Notochlamys*(?) *nanarupensis* sp. nov., RV, paratype with obvious shagreen in radial interspaces, WAM 72.46d, Nanarup Limestone (Aldingan), Nanarup Quarry, near Albany, Western Australia; enlarged, × 1.25.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appropriate for it. The fragmentary specimens from Abrakurrie Limestone, in particular, can be assigned to *Notochlamys* only tentatively, as none has even a reasonable fragment of an auricle, but the disc sculpture seems to lie within the range of variation of the Port Willunga Formation material. *Notochlamys*(?) *squamundata* differs from *Semipallium foulcheri* in all specimens having fewer, wider and more prominent plicae, and in most specimens having weaker radial costae, a larger size, and a less markedly prosocline disc shape than those of *S. foulcheri*. Also, a markedly higher proportion of specimens of *N. squamundata* has shagreen microsculpture than in *S. foulcheri*, in which shagreen is rare. In some cases the distinction is far from obvious and deserves more study.

Etymology. The specific name (Latin, '*squameus*', scaly + '*undata*', undulating, referring to the radial plicae) indicates the fine scaly sculpture on most specimens referred to the new species.

Notochlamys kendricki sp. nov.

Fig. 16A–F

Description. Average-sized for genus (most 40–45 mm high, reaching 55 mm), very weakly to quite obviously prosocline, umbonal angle narrow (95–100°); valves almost equally inflated—proximal area of disc slightly more inflated on RV than on LV, central area of disc slightly more inflated on LV than on RV. Sculpture of 7 or 8 extremely prominent, high plicae, each plica as wide as 2 plical interspaces on RV, with vertical to slightly undercut sides on RV, markedly narrower on LV than on RV, almost as high as wide on LV; plical crests weakly rounded on RV of most specimens, becoming slightly lower and more rounded on distal disc of large specimens, weakly sculptured to polished and almost smooth on proximal area of many specimens; strongly rounded on LV; radial costae low, almost smooth, 4 on plical crests of most RVs, up to 6 on distal disc of large specimens; 3 weak ones developing on plical crests of LV over distal disc of medium-sized specimens; 3 weak costae developing in RV interplical spaces over distal disc of medium-sized specimens and 3–6 in LV interspaces, all becoming prominent on distal third to half of disc on large shells; interplical spaces, plical sides and auricles bearing even, uniform, relatively fine shagreen microsculpture, forming a complete secondary surface, including on plical crests of some small unabraded specimens. Anterior auricles large, elongate, on RV with deep byssal notch and functional ctenolium retained in largest adults; posterior auricles small, short, with almost vertical posterior margins, posterior margins weakly concave in some specimens. Weak growth ledges present over distal third of disc of some specimens. Hinge with prominent resilial and dorsal teeth in RV, and corresponding resilial sockets in LV. Weak internal rib carinae commencing at about 35–40 mm disc height, becoming prominent on plical margins over distal third of large specimens.

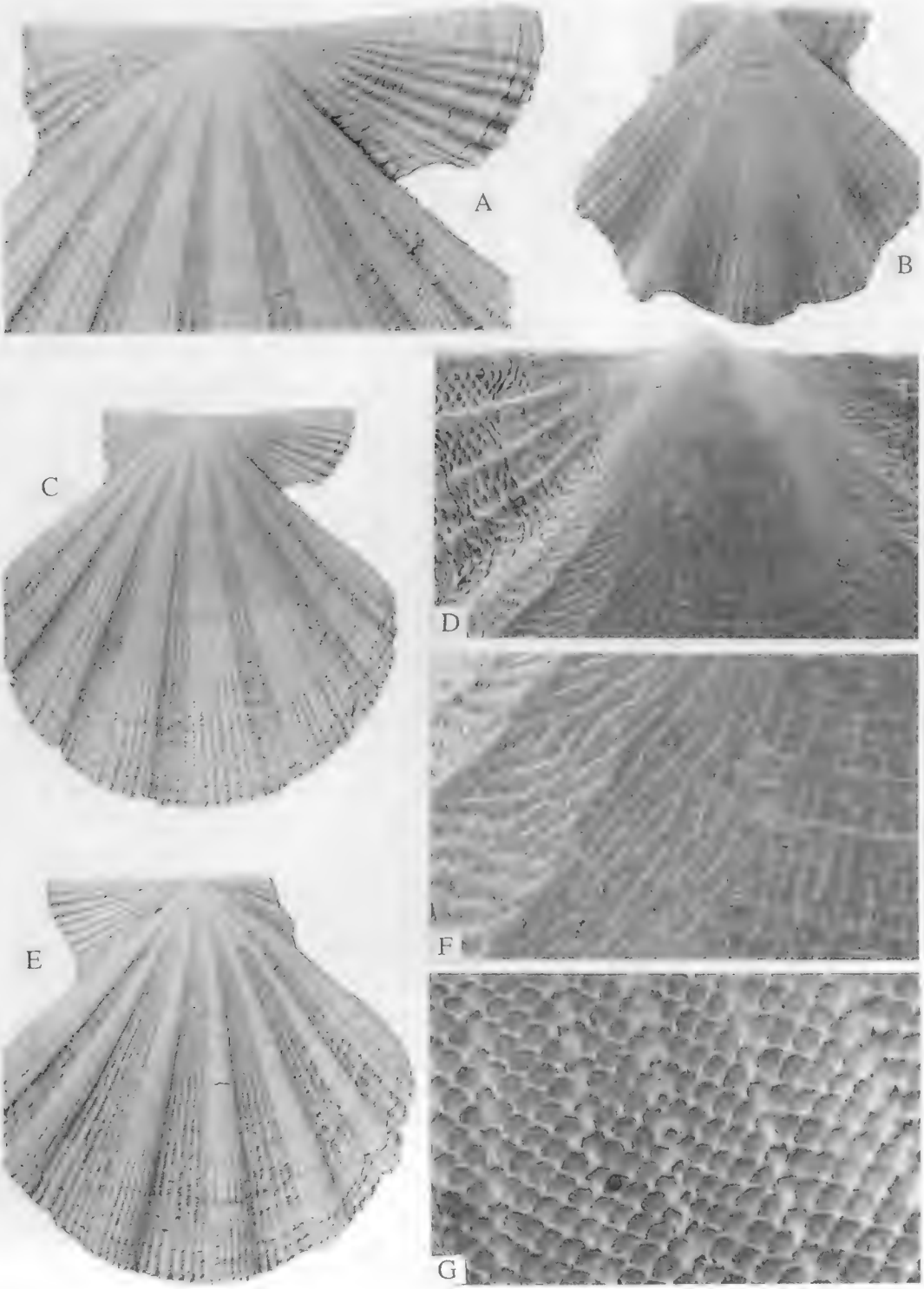
Dimensions.

Holotype			
WAM 81.887a	H 39.9	L 37.5	2 V articulated
Largest paratype			
WAM 79.1008b	56.1	57.0	RV
Paratype			
WAM 81.887b	46.3	45.2	2 V articulated
WAM 79.1008a	53.3	48.0	LV

Type material. Holotype, WAM 81.887a, Roe Calcarenite (Late Pliocene), basal 0.6 m of carbonate sand, in pit 0.5 km N of Hampton microwave repeater tower, Madura district, Roe Plains, Eucla Basin, coll. V. A. Ryland & G. W. Kendrick, 29.ix–4.x.1980; one paratype WAM 81.887b in same lot as holotype; 8 paratypes, WAM 79.1008a–h, 1.5 km N of Hampton Tower, basal 0.4 m carbonate sand, coll. V. A. Ryland & G. W. & W. E. Kendrick, 5–13.viii.1978; NMV P302790, one paratype, PL3167, pit 1.5 km N of Hampton Tower, coll. T. A. Darragh, 29.ix.1980.

Other material examined. **Late Pliocene:** ROE CALCARENITE: WAM 79.1002, 79.1003a–l, pit 1.5 km N of Hampton Tower, basal 0.4 m carbonate sand (13 specimens); WAM 94.836a–i, all data as holotype (9 specimens); WAM 81.607a, b, all data as holotype (2 specimens); WAM 79.1002, all data as holotype (one articulated pair); WAM 81.554, from mixed spoil, pit 0.5 km north of Hampton Tower (one articulated pair); AMS C90093, PL3172, Hampton Tower (3 specimens); NMV PL3167, pit 1.6 km N of Hampton Tower (10 specimens).

Fig. 16. A–F, *Notochlamys kendricki* sp. nov., all from Roe Calcarenite (Late Pliocene), basal 0.4 to 0.6 m in pits N of Hampton microwave repeater tower, Madura District, SE Western Australia: A, B, RV, paratype, WAM 79.1008b, interior and exterior, at natural size; C, F, LV and RV of paratype, WAM 81.887b, enlarged, × 1.25; D, E, LV and RV of holotype, WAM 81.887a, enlarged, × 1.25. G, H, *Notochlamys*(?) *nanarupensis* sp. nov., Nanarup Limestone (Aldingan), Nanarup Quarry, near Albany, Western Australia, at natural size: G, LV, holotype, WAM 69.235a; H, RV, paratype, WAM 69.234.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Occurrence and time range. The only records with precise stratigraphic data are from the basal 0.6–0.4 m of carbonate sand at and near the type locality, Roe Calcarenite (Late Pliocene), Roe Plains, southeastern Western Australia; the other material is not localised stratigraphically within the Roe Calcarenite.

Remarks. It is with a certain amount of hesitation that we separate *Notochlamys kendricki* sp. nov. from *N. hexactes*. The differences are slight, but constant. The most obvious distinction is in the number, width and prominence of the plicae which, although in *N. kendricki* only slightly more prominent than those of the most extremely coarsely plicate specimens of *N. hexactes* (notably the holotype; Dijkstra 1995: pl. 30, figs 130, 131), are consistently very prominent in *N. kendricki*, are raised higher above their interspaces, and have more nearly vertical to slightly undercut edges than in most specimens of *N. hexactes*. They are also a little wider on the RV, and correspondingly narrower on the LV, quite consistently in *N. kendricki* than in the most extreme *N. hexactes*. Also, presumably as a result of the narrower interspaces, there tends to be one more plica than on specimens of *N. hexactes* of the same size and proportions. A further distinction that seems to be constant is the markedly shorter posterior auricles of *N. kendricki* than of *N. hexactes*. Specimens of *N. kendricki* are also significantly to strongly prosocline in shape, in contrast to the very weakly prosocline to acline *N. hexactes*. Specimens of *N. kendricki* also tend to be significantly taller and narrower (with a narrower umbonal angle) than specimens of *N. hexactes*, although this difference is not constant. The few large specimens of *N. kendricki* we have seen, having concave, outwardly flared anterodorsal and posterodorsal margins, become wider and markedly more strongly prosocline than smaller specimens. Because of the very weak radial costae of most of the western (*anguineus* form) specimens of *N. hexactes*, the new species more nearly resembles the eastern (*tasmanica*) form, but specimens of this form tend to have lower plicae and much more prominent radial costae than *N. kendricki*.

There can be no doubt that *N. kendricki* is correctly assigned to *Notochlamys*, and its abundance in the basal carbonate sand of Roe Calcarenite makes it quite surprising that *Notochlamys* is otherwise almost unknown as a younger fossil in southern Australia. In particular, Hallett Cove Sandstone and Norwest Bend Formation in the St Vincent and Murray basins, respectively, are very similar to Roe Calcarenite in depth of deposition (all are very shallow-water, near-shore deposits) and in their faunal content, sharing almost all the same pectinids. The only obvious difference is that Roe Calcarenite is, as the name indicates, an unconsolidated limestone, lacking the terrigenous sand that is dominant in Hallett Cove Sandstone and Norwest Bend Formation. Even within Roe Calcarenite, *N. kendricki* has been collected only in the Hampton microwave tower area, perhaps reflecting the depth of the fossiliferous unit below the ground surface. The upper surface of Roe Calcarenite is a very hard calcrete sheet 30 cm thick, and the weathering and lithification decrease downwards; the unlithified basal carbonate sand is exposed in pits near the Hampton tower in uncomformable contact with a wave-planed surface of Abrakurrie Limestone. However, *Amusium balloti* is another pectinid that is present in Hallett Cove Sandstone and Norwest Bend Formation but, surprisingly, is absent from Roe Calcarenite, suggesting that these occurrences have an ecological explanation; *Notochlamys* and *Amusium* might well have different tolerances to sediment type and turbidity from other pectinids. However, it remains surprising that we know of no records of *Notochlamys* from Pliocene rocks of the Otway and Gippsland basins.

Etymology. We have great pleasure naming this species in honour of our colleague George W. Kendrick, Research Associate at the Western Australian Museum, to record his long, devoted research on the Cenozoic Mollusca of Western Australia and, in particular, on the Roe Calcarenite, and as an acknowledgement of the considerable assistance rendered to us for this paper.

Notochlamys hexactes (Lamarck, 1819)

Fig. 17A–G

Fig. 17. Notochlamys hexactes (Lamarck), Recent, type species of *Notochlamys* Cotton, 1930. A, C, E, AMS C119739, 'Tasmania', RV and LV of one specimen, enlarged, × 1.5 (C, E) and × 3 (A, RV auricles). B, D, F, G, AMS C300343, off Hood Point, Western Australia, 79 m, HMAS 'Gascoyne' Sta. G2/109/62, SEMs of juvenile LV; B, whole shell, × 9; D, F, preradial dissoconch sculpture enlarged, D × 35, F × 70; G, shagreen lower on disc, × 60.

Pecten hexactes 'Péron' Lamarck, 1819: 178; Deshayes, 1836: 154; Dijkstra, 1995: 492, pl. 30, figs 130, 131.
(?)*Pecten undulatus* Sowerby, 1842: 60, pl. 19, figs 206, 207; Reeve, 1852: pl. 20, fig. 73; Smith, 1885: 299; Tate & May, 1901: 441; Bavay, 1905: 22, 27; Hedley, 1916a: 157; Thiele, 1930: 591 (junior homonym of *Pecten undulatus* Nilsson, 1827).
Pecten tasmanicus A. Adams & Angas, 1864: 428, pl. 37, fig. 21a, b; Smith, 1885: 299; Bavay, 1905: 27.
Pecten mariae Tenison Woods, 1876: 158.
Chlamys undulatus [*sic*]; Pritchard & Gatliff, 1904: 263; Iredale, 1924: 194.
Chlamys anguineus [*sic*] Finlay, 1927: 527 (new name for *Pecten undulatus* Sowerby, 1842, preoccupied).
Notochlamys anguineus [*sic*]; Cotton, 1930: 233; Cotton, 1961: 98, fig. 83; Rombouts, 1991: 47, pl. 16, fig. 7a–c.
Mesopeplum tasmanicum; Macpherson & Gabriel, 1962: 305, fig. 347; Lamprell & Whitehead, 1992: pl. 14, fig. 81.
Decopecten [*sic*] *anguineus*; Coleman, 1975: 89, fig. 266.
Notochlamys tasmanica; Waller, 1991: 30, pl. 3, figs 11, 12; Rombouts, 1991: 48, pl. 18, fig. 1.
Mesopeplum anguineum; Lamprell & Whitehead, 1992: pl. 13, fig. 80.

Description. Moderate-sized (40–50 mm wide), most specimens slightly wider than high, large specimens markedly so; most specimens acline, some weakly prosocline; umbonal angle moderately wide (110–115°); rather weakly inflated, two valves about equally inflated. Disc folded into 5–11 plicae, on most specimens low, wide and rather closely spaced on RV and narrow, prominent and more widely spaced on LV; exterior sculptured with numerous low, narrow, closely spaced radial costae, increasing in number irregularly by subdivision of primary costae and by intercalation in interspaces, highly variable in prominence, width and number; many specimens from eastern part of modern range (*tasmanica* form) have many (7–11) low, narrow plicae and relatively numerous, prominent costae, whereas many specimens from western part of range (*anguinea* form, or typical hexactes) have fewer (5–7), more prominent, wider plicae with steep sides and much more numerous, very weak costae, but forms intergrade completely and are not strictly separated geographically. Anterior auricles long, in RV with moderately deep byssal notch and functional ctenolium retained in large adults; in LV long, tall, with strongly sinuous anterior margin, inclined strongly towards anterior at dorsum; posterior auricles small, tall, inclined weakly towards anterior. Interior with prominent ridges on edges of plicae, but developed into sharp rib carinae only on edges of narrower plicae of LV on most specimens, and on marginal area of coarsely costate specimens developed quite strongly on interior of many costae of both valves. Hinge teeth low and narrow; dorsal teeth in RV and corresponding sockets in LV obvious, moderately prominent infradorsal ridge in LV margined in RV by quite prominent resilial teeth and shallow sockets more dorsal to them.

Dimensions.

Holotype			
P. hexactes (Dijkstra, 1995: 493)	H 30	L 32	RV
AMS C119739, Tasmania	51.5	51.8	RV
As above	41.1	41.6	RV

Type material. Holotype of *Pecten hexactes* Lamarck, 1819, MNHN (Dijkstra 1995: pl. 30, figs 130, 131), from King George Sound, southern Western Australia. *Pecten undulatus* Sowerby, 1842, 5 syntypes BMNH 1951.3.28.4–5 (3 LVs and 2 RVs; Dr T. R. Waller 1999, pers. comm.); Sowerby (1842: 60) did not know the provenance of the type material, and suggested 'Mediterranean?', and it still needs to be clarified whether this nominal species actually is conspecific with *N. hexactes*. (Which introduces the possibility that the type species of *Notochlamys* was misidentified.) Dr T. R. Waller has informed us that the LV illustrated by Reeve (1852: pl. 20, fig. 73) is among these syntypes, but that illustrated by Sowerby (1842) is not present. Holotype of *Pecten tasmanicus* A. Adams & Angas, 1864, not seen, BMNH 1950.5.23.1 (H. H. Dijkstra, pers. comm.), from Oyster Bay, Tasmania; type material of *Pecten mariae* Tenison Woods, 1876, not seen, Tasmanian Museum TM 5749 (LV) (H. H. Dijkstra, pers. comm.) from 'East Coast and Maria Island', Tasmania.

Occurrence and time range. We know of no pre-Holocene fossil records. At present, *N. hexactes* ranges from southern Western Australia (AMS, 16 lots, northernmost Cottesloe Beach, Fremantle), South Australia (7 lots), Victoria (5 lots), and Tasmania (6 lots) to southern New South Wales (1 lot, the specimen recorded from Twofold Bay by Iredale 1924). Holocene fossils are present in WAM from Fremantle, lower Swan Estuary, East Rockingham, Cockburn Sound and Albany, all in southern Western Australia. The fossil record suggests that it may be a very recent arrival in southwestern Western Australia.

Remarks. Examination of a large range of material in AMS (35 lots) showed that a single, highly variable species of *Notochlamys* inhabits southern Australia, ranging (like most of the other endemic southern Australian scallops) from southern Western Australia to southern New South Wales, including all of Tasmania. The population is very variable in the width, number and prominence of the plicae, as well as in the number and coarseness of the radial costae and in shell color. Although specimens with numerous, narrow plicae and many relatively prominent costae (the *tasmanica* form) tend to predominate in the south and east of its range, and

specimens with relatively few, prominent, wide plicae and numerous weak radial costae (the *anguinea* form) tend to predominate in southern Western Australia, the two forms intergrade completely, the same variants occur throughout the range, and there is no doubt that this is a single, highly variable species. Specimens are illustrated here to compare with the fossil species referred to *Notochlamys*, and to determine the characters of the LV preradial dissoconch sculpture.

Dijkstra (1995: 492, pl. 30, figs 130, 131) has shown that Lamarck's (1819: 178) holotype of *Pecten hexactes* is a small, very coarsely plicate RV of the species usually known as *Notochlamys anguinea*, with six plicae, collected in King George Sound, southern Western Australia, by Péron.

Genus ***Semipallium*** Jousseaume in Lamy, 1928

Semipallium Jousseaume in Lamy 1928: 169.

Type species (by original designation). *Pecten tigris* Lamarck, 1819 (= *Ostrea flavicans* Linné, 1758; Dijkstra 1999: 426), Recent, Indo-West Pacific.

Belchlamys Iredale, 1929a: 164.

Type species (by original designation, Iredale 1929a: 188). *Pecten aktinos* Petterd, 1886, Pleistocene and Recent, southern Australia.

Remarks. Generic characters of *Semipallium* are its moderately narrow to very narrow umbonal angle and tall, narrow, strongly prosocline disc, associated with the retention of a deep byssal notch, a greatly elongated RV anterior auricle and a functional ctenolium in the adult; ie., species of *Semipallium* remain byssally attached throughout life. Other characters are the small posterior auricles, with a weakly concave posterior margin, the presence of quite fine shagreen microsculpture over most or all of the shell, the sculpture of about 9–11 relatively narrow, closely spaced plicae bearing many fine radial costellae, and the LV preradial dissoconch microsculpture of shallow but obvious, antimarginally elongate pits, passing outwards through a short zone of antimarginal ridgelets at about the position of inception of the costae, to grade into the shagreen. Waller (1991: 24–25) discussed the relationships with *Swiftopecten* and with *Manupecten* Monterosato, 1872 (type species: *Ostrea pesfelis* Linné, 1758, Recent, Mediterranean). He pointed out that *Manupecten* is very similar and closely related to *Semipallium*, differing mainly in bearing large, pustulose scales along the dorsal margin of the RV auricles that are absent from *Semipallium*. *S. fulvicostatum* (A. Adams & Reeve, 1850), a living tropical Pacific species closely resembling *S. flavicans* (Linné), is illustrated here (Fig. 18E–G) for comparison with *S. aktinos* and *S. foulcheri*.

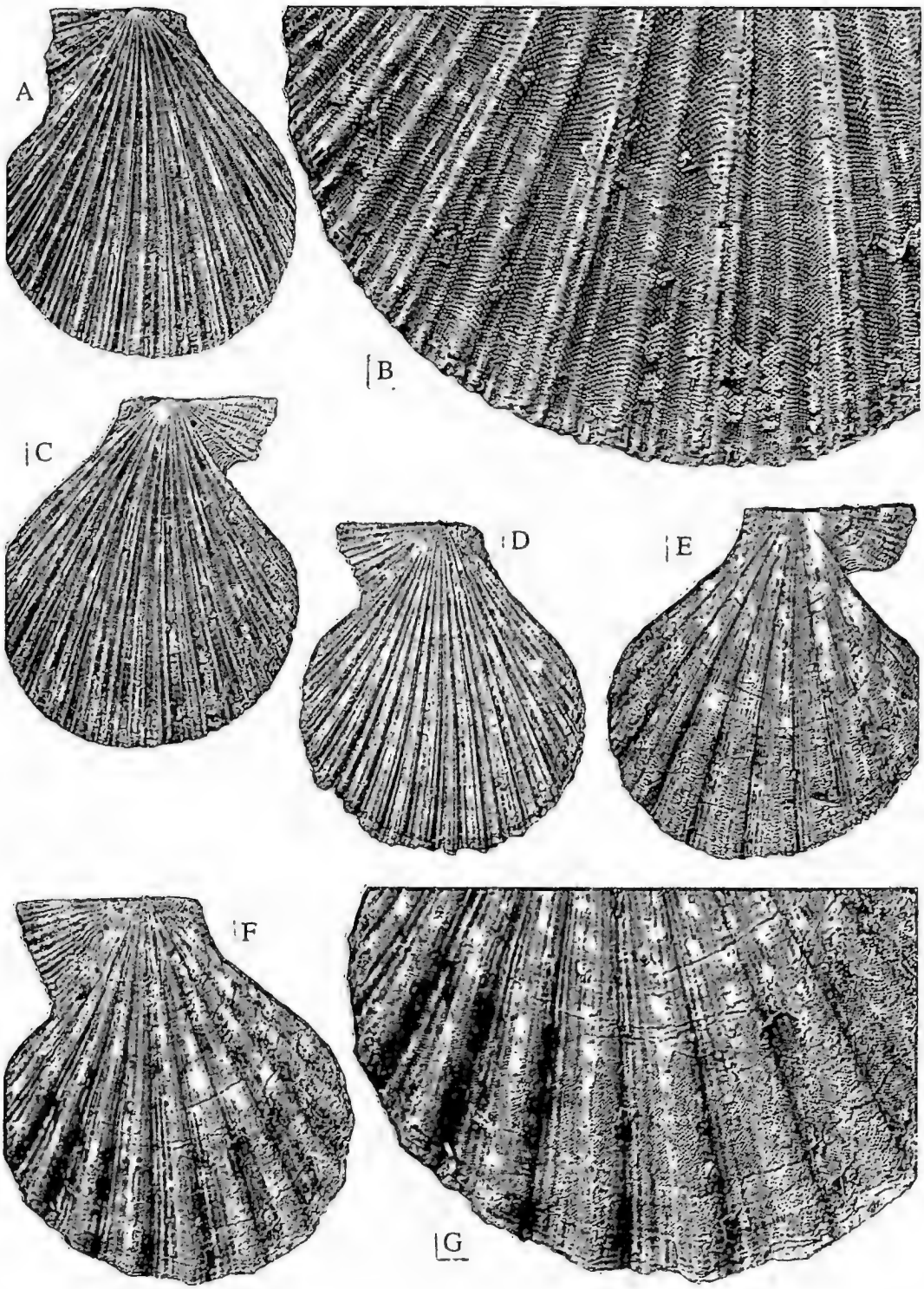
Iredale (1929a: 164) proposed *Belchlamys* for the widespread southern Australian species *Pecten aktinos* Petterd (misspelled '*atkinos*' by several authors). This is very relevant here as, not only is '*Chlamys*' *aktinos* represented in the fossil record of the Perth Basin, but also it closely resembles the most abundant and widespread of all the Australian fossil scallops, '*Chlamys*' *foulcheri* (Tenison Woods). If *Belchlamys* were to be recognised as a genus, this would be the logical position for '*Chlamys*' *foulcheri* and similar fossils. However, comparison of a wide range of material of '*Belchlamys*' *aktinos* showed that the common finely costate form grades into an uncommon form (Figs 18A–D, 21B) with coarser costae, grouped together to form low, narrow plicae. This form is indistinguishable in all characters from *Semipallium*. *Belchlamys* is here regarded as a synonym of *Semipallium*, and the southern Australian fossil and living species are referred to *Semipallium*.

Semipallium foulcheri (Tenison Woods, 1865)

Figs 19A–H, 20A–I

Pecten sp. Sturt, 1833: 254, pl. 3, fig. 14.
Pecten foulcheri Tenison Woods, 1865: 1, fig. 3; Tate, 1886: 111; Pritchard, 1896: 127; Tate, 1899: 270.
Pecten praecursor Chapman, 1912: 36, pl. 5.
Notochlamys antecedens Singleton, 1941: 427 (unnecessary replacement name for *Pecten praecursor* Chapman, 1912, not *Pecten precursor* Dall, 1898).

Description. Moderate-sized (*c*. 40–55 mm high), slightly taller than wide to, in most large specimens, slightly wider than high; moderately to quite strongly prosocline; umbonal angle moderate (*c*. 100–105°); weakly to moderately inflated, the two valves about equally inflated. Exterior sculpture commencing as 8–10 low, narrow, widely spaced primary costae, remaining simple and undivided or becoming complexly subdivided and intercalated across disc to produce an exceedingly variable range of sculpture, from 8–10 very prominent, narrow, widely spaced costae with long, flat to weakly ventrally cupped, ventrally inclined scales along costal crests and wide, deeply concave costal interspaces, to 60–70 low, narrow, closely spaced, subequal, finely scaly costae, on some specimens arranged on low to quite prominent plicae, ranging from 18–20 low, narrow, weak plicae to 8–10 more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prominent ones; shagreen microsculpture present on all costal interspaces of most moderately to coarsely sculptured specimens, not present on most finely sculptured specimens. RV anterior auricle remaining long and narrow and retaining deep, narrow byssal notch and functional ctenolium in all specimens, anterior extremity long and narrowly pointed on some specimens; LV anterior auricle long, high, sloping towards anterior, anterior margin weakly concave to weakly sinuous; posterior auricles short, small, posterior margin weakly to quite strongly concave, sloping towards anterior. RV hinge with obvious long, narrow dorsal teeth and low, very narrow, widely diverging ridges alongside dorsal half of resilifer; LV with sockets for RV dorsal teeth, margined below by low infradorsal ridges, and with very low, narrow resilial ridges diverging at markedly lower angle than in RV, and apparently fitting towards resilifer, inside RV ridges.

Dimensions.

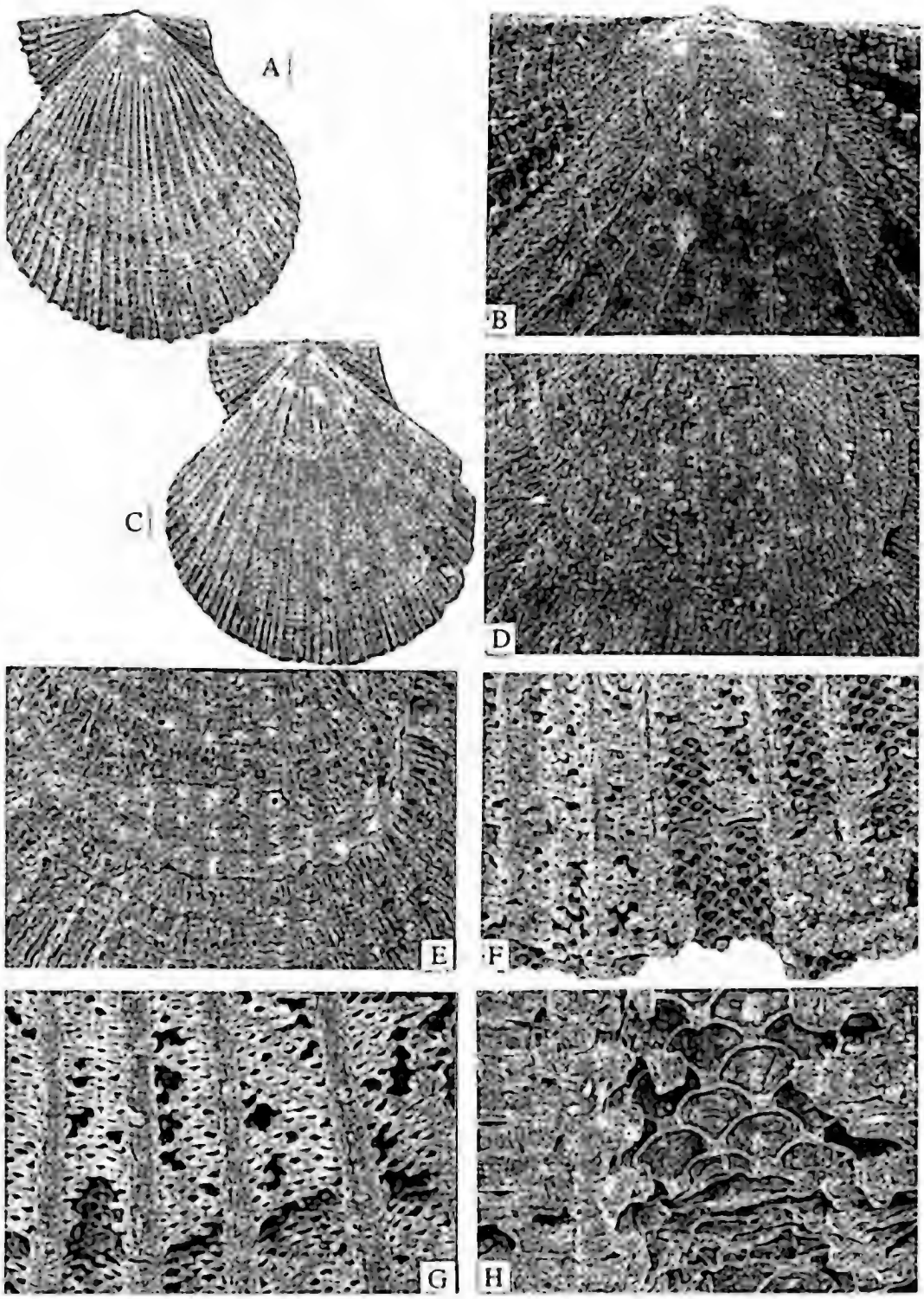
Neotype			
NMV P302198 (incompl.)	H 52.3	L 49.9	RV
NMV P302064, Blanchetown	45.3	44.3	LV
NMV P302065, Blanchetown	44.5	46.1	RV
NMV P302066, Blanchetown	40.6	40.1	LV
NMV P302067, Blanchetown	37.5	35.6	RV
NMV P302068, Blanchetown	28.2	26.0	RV

Type material. The whereabouts of the type material of the pectinids named by Tenison Woods (1865) is unknown (*Pecten foulcheri*, *P. gambierensis*, *P. incertus* and *P. yahliensis*). The Rev. J. E. Tenison Woods moved about frequently between remote small towns in South Australia during this early period of his paleontological career. His collections from this period could therefore have been stored at any of several locations, and have not been traced by later workers, despite many attempts. It seems reasonable to assume that the type material of all four species proposed by Tenison Woods (1865) is lost, and we propose neotypes for them all here. This is particularly important for *P. foulcheri*, given its great range of variation and the fact that other names have been proposed that we believe are synonyms. The type locality for this species was cited as 'Somewhat common at Mount Gambier, but nearly always found in a broken state'. We visited the Mount Gambier area for the specific purpose of collecting specimens of the three species from Mount Gambier, *P. foulcheri*, *P. gambierensis* and *P. yahliensis*, in order to (a) understand Tenison Woods' species, and (b) establish neotypes from as near as possible to the type locality. At the numerous quarries excavated to work Gambier Limestone, *Semipallium foulcheri* unfortunately is one of the least common pectinids. We designate as the neotype of *Pecten foulcheri* Tenison Woods a small, nearly complete LV, NMV P302198 (Fig. 20A), bearing obvious, fine shagreen in all major radial interspaces, from Gambier Limestone in a quarry at the northeast corner of the junction of Siggers and Mitchell roads, west of Mt Gambier, grid ref. Schank 705125, coll. A. G. Beu & T. A. Darragh, 10.xi.1993; from Gambier Limestone, here Janjukian. A large, incomplete RV (P302071) from the same locality also is illustrated (Fig. 20C).

Pecten praecursor Chapman, 1912, holotype, NMV P12590, from Jan Juc Formation (Janjukian), 'Spring Creek', Torquay, Victoria, ie., Bird Rock cliffs, coast south of Melbourne (a small, complete LV); paratype, NMV P12591, Waurn Ponds Limestone (Janjukian), Waurn Ponds lime quarry, near Geelong, Victoria, ex Geological Survey of Victoria (an incomplete RV); paratype, NMV P12592, Curlewis (Batesfordian), near Geelong, Victoria, ex Geological Survey of Victoria (a badly broken RV, now in two pieces).

Other material examined. **Willungan:** PORT WILLUNGA FORMATION: PL6669, south of Onkaparinga Trig (20 specimens). **Janjukian:** GAMBIER LIMESTONE: PL3237, Butler's Quarry (4 specimens); PL3238, Commercial Minerals Quarry (1 specimen); quarry NW corner of Siggers and Mitchell rds, W of Mt Gambier (6 specimens); Knight & Pritchard's Quarry, Mt Gambier (6 specimens); railway quarry 12 km NNW of Mt Gambier (4 specimens); CALDER RIVER LIMESTONE: GSV Aw3 (19 specimens); PL3020, GSV Aw4 (17 specimens); Aire Coast (9 specimens); Spud Point, Glen Aire, in front of Robinson's house (2 specimens); quarry, left bank Calder River, Horden Vale, Aire 367 175 (1 specimen); Calder River, Horden Vale (3 specimens); CLIFTON FORMATION: Loves Creek, Kawarren (1 specimen); PL3552, Kawarren limestone quarry (12 specimens); coast at Princetown (1 specimen); base of limestone 0.8 km NW of Point Ronald, Princetown (3 specimens); 80 chains NW of Point Ronald, Princetown (1 specimen); MANDU CALCARENITE: WAM 95.577–9, 200–300 m upstream from road along canyon floor, second tributary from head of canyon entering from north, Shothole Canyon, Cape Range, Carnarvon Basin (3 specimens); JAN JUC FORMATION: PL3024, Bird Rock cliffs (24 specimens); PL3025, Fishermans Steps, Torquay (11 specimens); 200 m S of Fisherman Steps, Torquay (1 specimen); Torquay cliffs (30 specimens); Spring Creek, Torquay (36 specimens); AMS F2010, Jan Juc, Torquay (1 specimen); WAURN PONDS LIMESTONE: PL3278,

Fig. 18. A–D, *Semipallium aktinos* (Petterd), Recent, southern Australia: A–C, AMS C103821, Black River Beach, northern Tasmania, enlarged, × 1.5 (A, LV, and C, RV); B, ventral area of A, enlarged, × 3; D, LV, AMS C99888, S side of Two Peoples Bay, near Albany, southern Western Australia, enlarged, × 1.5. E–G, *Semipallium fulvicostatum* (A. Adams & Reeve), Recent, a tropical species closely resembling *S. flavicans* (Linné), type species of *Semipallium* Jousseaume in Lamy 1928; AMS C153321, 8–13 m, Reef 14-151, Great Barrier Reef, North Queensland: E, F, RV and LV of one specimen, enlarged, × 1.5; G, ventral area of LV enlarged, × 3.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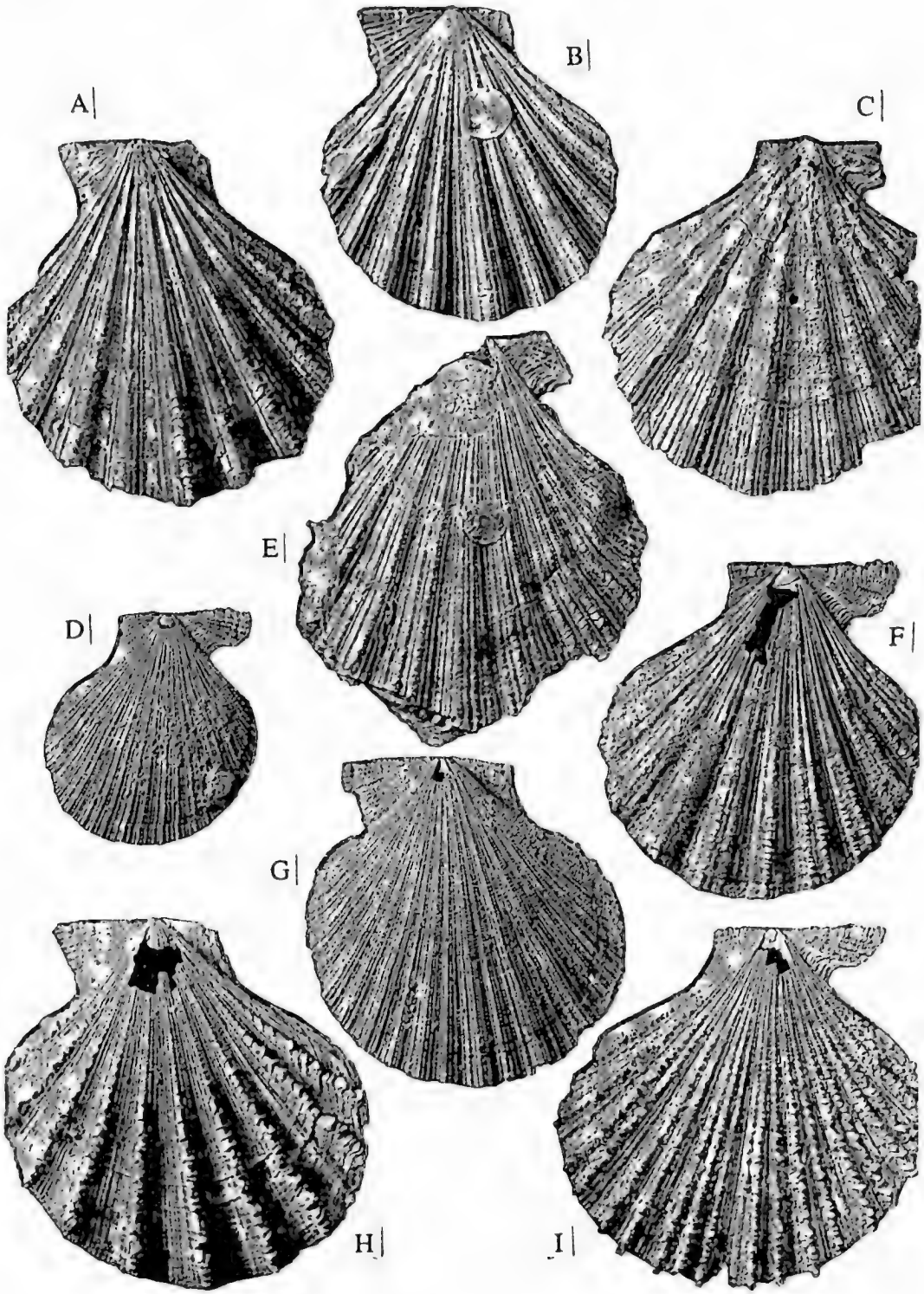
Blue Circle Southern Cement Quarry (10 specimens); Ad 26, quarry on Colac Road (37 specimens); Clyde Quarry, Waurn Ponds (11 specimens); Morandez Quarry, off Cochranes Road, Waurn Ponds (1 specimen); N side Cochranes Road, 0.6 km from Princes Hwy, Waurn Ponds (14 specimens); Waurn Ponds (105 specimens); Thompsons Creek, Mount Moriac (2 specimens); LOWER MAUDE LIMESTONE: Tm1, Parish of Darriwill (4 specimens); Maude (3 specimens); POINT ADDIS LIMESTONE: PL3277, Point Addis (7 specimens); Aireys Inlet (30 specimens); E of Rocky Point, near Torquay (1 specimen); PORT WILLUNGA FORMATION: PL3287, Esplanade, Port Vincent (1 specimen). **Longfordian:** FOSSIL BLUFF SANDSTONE: PL3029, Fossil Bluff (26 specimens); FREESTONE COVE SANDSTONE: PL3028, lower bed, Freestone Cove (101 specimens); Table Cape (34 specimens); GAMBIER LIMESTONE: PL3219, quarry, Nelson North Rd (1 specimen); PL3223, quarry, Border Rd (4 specimens); PL3234, pit, Earls Cave Rd (3 specimens); PL3224, quarry, Dry Creek Valley (5 specimens): PL3225, quarry, Bonds Rd (15 specimens); PL3226, Glenelg River at Donovans (1 specimen); PL3227, entrance to Amphitheatre Cave (1 specimen); PL3230, ACI lime quarry (1 specimen); PL3231, quarry, Donovans Rd (15 specimens); PL3232, quarry, Galpins Rd (2 specimens); PL3233, quarry, Tervorft Rd (6 specimens); PL3235, Gambier Earth Movers quarry (6 specimens); PL3239, quarry, Tolmie Street, Mt Gambier (4 specimens); PL3241, Telford's fish ponds (2 specimens); Mount Gambier (28 specimens); Umpherstons Cave, Mt Gambier (2 specimens); quarry on main highway, 0.8 km E of Tantanoola, SA (1 specimen); Glenelg River cliff opposite Dry Creek, SA (1 specimen); Port MacDonell, SA (2 specimens); quarry, allot. 35, Parish of Derholm, Victoria (1 specimen); allot. 2, parish of Roseneath, Victoria (2 specimens); WAM 78.894, *limestone quarry, Mount Gambier* (1 specimen); GELLIBRAND FORMATION: Birregurra (29 specimens); GIPPSLAND LIMESTONE: PL3250, Calcimo Quarry (6 specimens); PL3251, Merrimans Creek quarry (28 specimens); PL3254, Gippsland Cement Quarry (1 specimen); PL3255, Darriman Quarry (14 specimens); Dutson Quarry, Longford (1 specimen); Robinson's Quarry, Dutson (1 specimen); Longford (10 specimens); GLENELG GROUP: Allot. 26A, Parish of Bahgallah (1 specimen); Allot. 11, Parish of Bahgallah (13 specimens); Greenwald landslip (3 specimens); MANNUM FORMATION: PL3180, Sunnyside Lookout (13 specimens); PL3188, Mannum pumping station (1 specimen); PL3190, Underwood Hill road cutting (1 specimen); PL3191, cutting, Klose Rd, 6 km N of Mannum (14 specimens); PL3193, Wongulla (6 specimens); PL3194, Walker Flat (43 specimens); PL3195, Murray cliffs, Swan Reach (45 specimens); PL3196, Big Bend Reserve (35 specimens); PL3199, Murray cliffs, 'Cooinda' (22 specimens); PL3201, base of Blanchetown Bridge (11 specimens); PL3209, Good Hope Landing (51 specimens); PL3210, Woolpunda Pumping Station (1 specimen); PL3212, Murray cliffs, 'Cave Cliff ' (50 specimens); PL3218, Murray cliffs, 'Yarra Glen' (27 specimens); Mannum, SA (2 specimens); left bank Murray River, Punyelroo (5 specimens); Murray cliffs, Swan Reach (1 specimen); Murray cliffs, Wongulla (10 specimens); Lower beds, River Murray cliffs, Overland Corner (11 specimens); WAM 94.364, Mannum (1 specimen); WAM 95.291, Swan Reach, SA (1 specimen); WAM 94.368, Nildottie (3 specimens); WAM 92.732, near *Woolpunda pumping station, 20 km S of Waikerie, Murray* River (1 specimen); WAM G-6938, Mannum (1 specimen); AMS F5897, F5898, cliffs 30–40, Overland Corner to Holder, SA (4 specimens); AMS C133472, Murray River (1 specimen); AMS F135, Swan Reach caves, SA (1 specimen); AMS F5887, cliff 69, Parish of Murbko, Murray River (1 specimen); AMS F5889, cliff 78, Parish of Ridley, Murray River (1 specimen); MARRAWAH LIMESTONE: Marrawah picnic ground, Marrawah Beach, Tasmania (4 specimens); NARACOORTE LIMESTONE: PL3245, Comaum Forest quarry (5 specimens); PL3246, Elderslee Quarry (17 specimens); PL3247, James Quarry (8 specimens); AMS C122943, Naracoorte (1 specimen); PORT WILLUNGA FORMATION: PL3597, Angle Vale bore (29 specimens); PUEBLA FORMATION: PL3032, Jan Juc Beach (17 specimens); Ad 20, mouth of Spring Creek (2 specimens); Torquay (17 specimens); mouth of Jan Juc Creek, Torquay (5 specimens); Yellow Bluff, Torquay (3 specimens); polyzoal limestone, cliff north of Bird Rock, Torquay (16 specimens); ZEALLY LIMESTONE: Jan Juc Point, mouth of Spring Creek, Torquay (7 specimens); between Torquay and Jan Juc Creek (1 specimen); FISHING POINT MARL: PL3035, SE of Fischers Point (7 specimens); PL3036, NW of Red Hill (5 specimens); SANDFORD LIMESTONE: PL 3161, Runnymede Road quarry (3 specimens); Jackson's Bluff, Glenelg River (4 specimens); UPPER MAUDE LIMESTONE: WTm2, east bank Moorabool River (10 specimens); WTm1, Moorabool River (10 specimens); Maude (30 specimens). **Batesfordian:** BATESFORD LIMESTONE: *Upper quarry, Batesford (2 specimens)*; Batesford (1 specimen); Batesford Lime Quarry (1 specimen); new quarry, Batesford (1 specimen); FLINDERS LIMESTONE: PL3055, Flinders (1 specimen); Flinders (4 specimens); GAMBIER LIMESTONE: PL3236, pit on McLeans Rd (1 specimen); GELLIBRAND FORMATION: PL3048, Bornong Rd (3 specimens); PL 3049, Serpentine Creek (5 specimens); PL3163, Williams Rd (3 specimens); FYANSFORD FORMATION: PL3038, Ad 14, Curlewis (3 specimens); PL3039, Ad 12, Curlewis (14 specimens); PL3041, Fc20, Yarrowee River (3 specimens); Belmont Shaft (4 specimens); Curlewis (44 specimens); WUK WUK MARL: PL3054,

Fig. 19. Semipallium foulcheri (Tenison Woods), SEMs of juvenile LVs, showing sculpture of preradial dissoconch, and shagreen lower on disc. A, E, G, P300271, Port Willunga Formation (here Longfordian), bore 17-2, 'Sylvan Glades', Angle Vale, South Australia: A, whole shell, × 4 (H 12.6 mm); E, coarse microsculpture at costal inception, enlarged, × 40; G, shagreen near centre of disc, × 30. B–D, F, H, P300423, Fyansford Formation (Balcombian), Balcombe Bay, Mornington, Victoria: C, whole shell, × 4; B, D, sculpture of preradial dissoconch, enlarged (B × 30, D × 55); F, H, shagreen at ventral margin, enlarged (F × 25, H × 100).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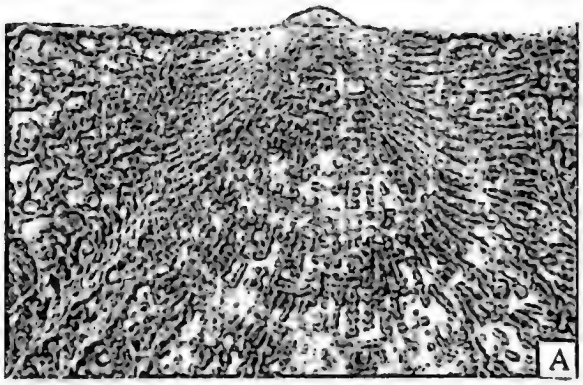
Skinners (5 specimens). **Balcombian:** BOCHARA LIMESTONE: Grange Burn, near Henty's (7 specimens); Natural Arch, Grange Burn (2 specimens); CADELL MARL: PL3084, 6.4 km below Morgan, SA (25 specimens); COLVILLE SANDSTONE: WAM 88.908, surface float, 16 km W of Lake Colville, Nullarbor Plain (1 specimen); WAM 94.353, Lake Colville, northern Nullarbor region (3 specimens); FYANSFORD FORMATION: Ad 16, Corio Bay, Geelong (1 specimen); PL3078, Fossil Beach (55 specimens); Green Gully, Keilor (4 specimens); Lake Connewarre (11 specimens); Ad 8, east of Lake Connewarre (1 specimen); Shelford (1 specimen); WAM 82.620, McCamm's lime quarry, Fyansford (1 specimen); MORGAN LIMESTONE: PL3189, access road, Mannum pumping station (9 specimens); PL3197, N of Greenways Landing (9 specimens); PL3198, Blanchetown Bridge cutting (274 specimens); PL3200, 2.4 km S of Moorundie (12 specimens); PL3202, Adams St, Blanchetown (14 specimens); PL3203, S. Australian Water Ski Assoc. (105 specimens); PL3205, Woods Flat Post Office (92 specimens); PL3208, Great Yarra Reach (34 specimens); PL3211, Murray cliff at 'Karelia' (20 specimens); PL3214, 3.5 km SE of Cadell (1 specimen); PL3217, top of Murray cliffs, 'Yarra View' (5 specimens); PL6668, Overland Corner (1 specimen); white calcareous bed, Murray cliffs at Morgan (82 specimens); Murray cliffs at Morgan (11 specimens); Murray cliffs at Northwest Bend (2 specimens); WAM, Murray cliffs 6.4 km N of Blanchetown (31 specimens), Blanchetown (2 specimens); WAM 93.482, Blanchetown (1 specimen); WAM 70.1867, Morgan, Murray River (3 specimens); AMS F5896, Overland Corner to Holder, Murray River (2 specimens); MUDDY CREEK FORMATION: PL3082, Clifton Bank, Muddy Creek (23 specimens); AMS F483, Muddy Creek (1 specimen); GIPPSLAND LIMESTONE (here Balcombian): railway cutting, Newmerella (1 specimen). **Bairnsdalian:** FYANSFORD FORMATION: AMS, PL3104, cliffs S of Manyung Rocks (many; but *mislocalised?—none in extensive* Museum Victoria collection from this locality).

Occurrence and time range. Latest Willungan to Balcombian, although recorded (spuriously?) from one Bairnsdalian locality. Much the most wide-ranging and abundant of Australian Cenozoic pectinids, ranging from the Lower Miocene Mandu Calcarenite of the Carnarvon Basin, in Western Australia, to the Gippsland Basin and Bass Basin.

Remarks. *Semipallium foulcheri* is very much the most abundant, variable and widespread of all Australian Cenozoic fossil Pectinidae, comparable only with Plio-Pleistocene records of *Mimachlamys asperrima*. It is variable in shape, in the presence or absence of shagreen microsculpture within one population and, above all, in the coarseness of the radial sculpture. With very large collections from several localities available before us, we have tried many methods of subdividing the material into more than one species, without success. About 30–40% of specimens in most collections have costae grouped into low to quite prominent plicae. A small range of specimens from the characteristic, very highly varied population in Morgan Limestone, Murray Basin, is illustrated (Fig. 20F–I) to give some idea of the range of variation. Many of the more coarsely sculptured specimens in all populations have shagreen microsculpture in intercostal spaces, whereas most finely and closely sculptured specimens do not bear shagreen. Although the shape is wider relative to shell height than in most other species assigned to *Semipallium* (length about equal to height, or slightly greater than height in most large specimens, with a wider umbonal angle and a much less strongly prosocline shape than most other *Semipallium* species), *S. foulcheri* agrees with *Semipallium* in other significant characters, and seems correctly referred here. The inner ventral margin lacks any sign of internal rib carinae, and the hinge has low, narrow, resilial and dorsal teeth.

Specimens from Fyansford Formation (Balcombian) at Balcombe Bay, Mornington Peninsula, near Melbourne, and some of the specimens from Muddy Creek Formation (Balcombian) at Muddy Creek, western Victoria, are very evenly rounded in outline and have radial sculpture of very evenly and consistently rounded, low plicae with interspaces a mirror image of the plicae, and many fine, closely spaced, closely subdivided secondary and tertiary costellae, all sculptured with many low scales on costal crests and, unlike most other finely sculptured specimens, all bear coarse, obvious shagreen in intercostal spaces. In view of the consistency of this form at Balcombe Bay, and the absence of other forms there, this is

Fig. 20. Semipallium foulcheri (Tenison Woods). A, neotype (designated here) of *Pecten foulcheri* Tenison Woods, P302198, small LV bearing shagreen, Gambier Limestone (Janjukian), quarry on E side of junction Siggers and Mitchell roads, W of Mount Gambier, South Australia, enlarged, × 2. B, LV, holotype of *Pecten praecursor* Chapman, 1912 (= *Notochlamys antecedens* Singleton, 1941), P12590, Jan Juc Formation (Janjukian), 'Spring Creek', Torquay, Victoria, enlarged, × 2. C, large RV from same locality as neotype, P302071, at natural size. D, F–I, P302064–302068, 5 specimens (from a much larger suite) in one collection, Morgan Limestone (Balcombian), 'River Murray cliffs, Morgan and district', ex Cudmore Coll., all enlarged, × 1.25: D, F, I, RVs; G, H, LVs. E, RV, incomplete paratype of *Pecten praecursor* Chapman, P12591, Waurn Ponds Limestone (Janjukian), Waurn Ponds, near Geelong, Victoria, enlarged, × 1.5.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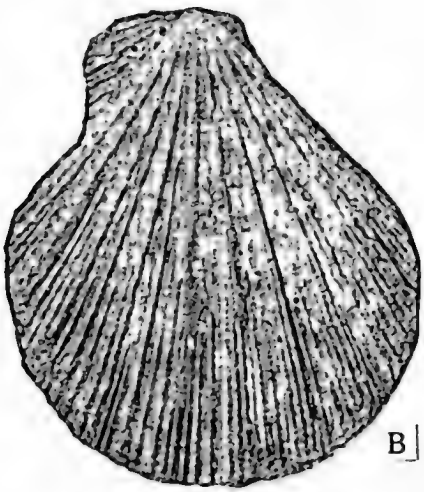
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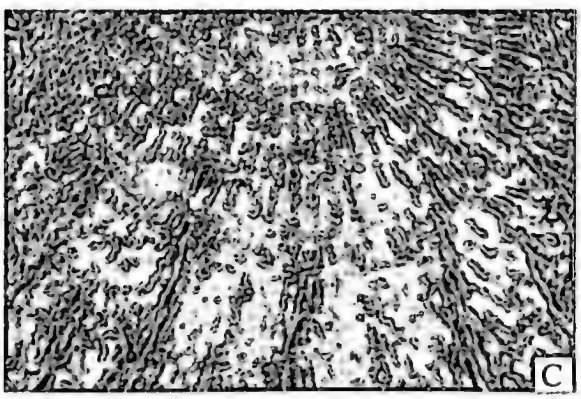
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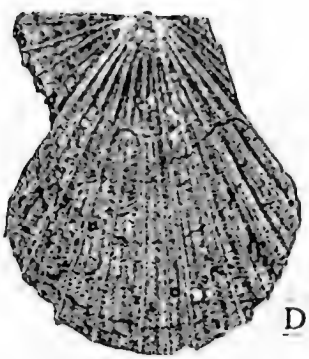
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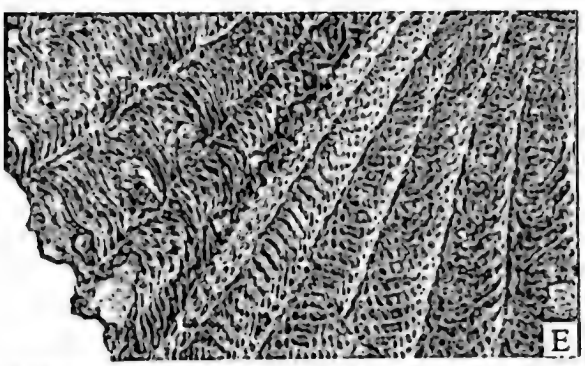
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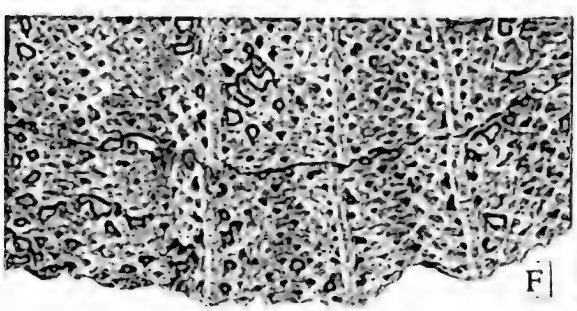
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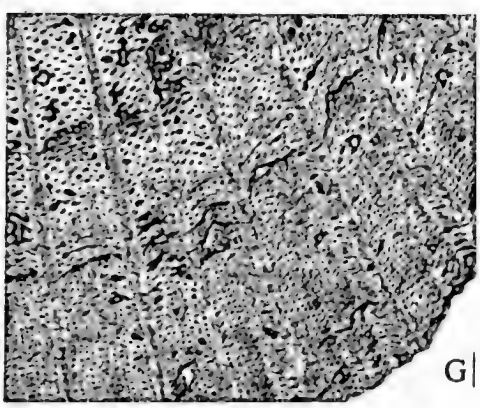
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perhaps a species distinct from *S. foulcheri*, but because of the enormous range of variation of undoubted *S. foulcheri*, we are at a loss to know how to otherwise characterise it. It is feasible that *S. foulcheri* is a species of low-turbidity water (so found mainly in limestone) whereas the Balcombe Bay form is a separate species occurring in more turbid silty environments, but it is equally likely, the morphological differences may be merely ecophenotypic. It should be noted that the specimens studied by SEM (Fig. 19B–D, F–H) are from Balcombe Bay.

A single lot of 29 small specimens (largest 18 mm high) from Port Willunga Formation in a bore on 'Sylvan Glades', Angle Vale, South Australia (here Longfordian in age; Lindsay 1969; bore 24) resembles *S. foulcheri* in most characters, but has markedly more prominent commarginal ridges and antimarginal ridgelets on the LV preradial and early radial dissoconch (Fig. 19A, E) than the examined specimens of *S. foulcheri* (Fig. 19B–D, F–H) from Fyansford Formation at Balcombe Bay. In view of the fact that this is the only material we have seen of this group from St Vincent Basin, we tentatively retain this lot in *S. foulcheri*. More study of a wider range of well preserved material of early lots assigned to *S. foulcheri* may well demonstrate that more than one species is present.

Chapman (1912: 36) established *Pecten praecursor* for '*Pecten consobrinus* Tate, var.', and based it on specimens of *S. foulcheri* lacking shagreen microsculpture. As noted above, the species is highly variable in this character, and there is no doubt that *P. praecursor* is merely part of the variation of *S. foulcheri*. Singleton (1941: 427) provided the new name *Notochlamys antecedens* for *Pecten praecursor* Chapman because he thought it was preoccupied by *Pecten precursor* Dall, 1898, although under the present ICZN code these names are not homonyms.

Semipallium aktinos (Petterd, 1886)

Figs 18A–D, 21A–G

Pecten aktinos Petterd, 1886: 320.
Pecten bednalli Tate, 1887b: 73, pl. 4, fig. 3a.
Chlamys bednalli; Hedley, 1900: 495, pl. 25, figs 10–13.
Pecten actinos [*sic*]; Tate & May, 1901: 441.
Chlamys aktinos; Pritchard & Gatliff, 1904: 265; Hedley, 1918: M8; May, 1921: 10; 1923: pl. 3, fig. 10; Wells & Bryce, 1985: 158, fig. 580.
?*Notochlamys hallae* Cotton, 1960: [1], 2 unnumbered figs; Cotton, 1961: 99, fig. 85; Rombouts, 1991: 47.
Belchlamys atkinos [*sic*]; Cotton, 1961: 100, fig. 86.
Mimachlamys aktinos; Iredale & McMichael, 1962: 11.
Chlamys atkinos [*sic*]; Macpherson & Gabriel, 1962: 303, fig. 345.
Chlamys (Belchlamys) aktinos; Rombouts, 1991: 22, pl. 8, fig. 5; Lamprell & Whitehead, 1992: pl. 9, fig. 49.
?*Semipallium hallae*; Lamprell & Whitehead, 1992: pl. 12, fig. 71.

Description. Moderate-sized (33–40 mm high), tall and narrow, weakly to moderately prosocline, with narrow umbonal angle (85°) and weak inflation; the two valves about equally inflated, RV very slightly more inflated than LV in some specimens. Exterior sculpture of *c.* 9–11 low, narrow, widely spaced primary radial costae, some of which subdivide very early on RV to form 18–20 narrow costae, remaining undivided until a little later on LV, all then increasing by subdivision and intercalation to produce 60–80 fine, narrow, closely spaced, weakly scaly costae near ventral margin of most specimens, grouped on *c.* 20% of specimens on crests of 9–11 more prominent costae, or narrow, closely spaced plicae; in some specimens narrow costae arranged as fasciculate groups on plical crests; radial interspaces remaining quite wide and gently concave on all specimens, bearing obvious shagreen microsculpture on all specimens. RV anterior auricle moderately long and narrow (ie., shorter than in many other chlamydoid pectinids), with deep, narrow byssal notch and functional ctenolium in adults; LV anterior auricle short but high, with obviously sinuous anterior margin inclined towards anterior; posterior auricles tall but very narrow, inclined strongly towards anterior, with weakly concave posterior outline. Hinge narrow and weak, with low, narrow dorsal and resilial teeth in RV, and shallow sockets for dorsal teeth margined below by infradorsal ridges, and very short, thin resilial teeth beside dorsal half of resilifer in LV.

Fig. 21. Semipallium aktinos (Petterd), Recent specimens. A, C–G, SEMs of juvenile LV, AMS C300339, HMAS 'Moresby' Sta. 6, off Green Head, southern Western Australia; whole shell enlarged, × 10 (D) and enlargements of sculpture of preradial dissoconch (A × 60, C × 75) and of shagreen (E, F × 50, G × 30), for comparison with Fig. 19C–D, F, G. B, large LV, AMS C119532, Flinders, Westernport Bay, Victoria, enlarged, × 1.5.

Dimensions.

WAM 71.138			
Paulik's bore, Jandakot	H 28.6	L 24.2	LV
AMS C103821			
Black River Beach, N Tasmania	35.3	30.4	RV
AMS C119532			
Flinders, Western Port, Victoria	40.9	35.5	LV

Type material. Petterd (1886) gave only the general locality 'North-West coast' [of Tasmania] for *Pecten aktinos*; the type is assumed to be in the Tasmanian Museum, Hobart. Type material of *Pecten bednalli* Tate SAM D14170 (H. H. Dijkstra, pers. comm.); stated by Tate (1887b: 73) to be from Aldinga Bay, near Adelaide. Holotype of *Notochlamys hallae* SAM D16541, Hall Collection (H. H. Dijkstra, pers. comm.); from Largs Bay, South Australia.

Other material examined. **Recent:** AMS, 66 lots, from Western Australia (24 lots, as far north as Dongara); South Australia, 10 lots; Victoria, 4 lots; Tasmania, 5 lots; New South Wales, 10 lots; Queensland, 13 lots; Northern Territory, 1 lot (AMS, C132630, Gove, N Arnhem Land, 1979–80, coll. Mrs J. Woodhouse, 2 V). *Fossils:* **Early Pleistocene:** 'YOUNGER' ASCOT FORMATION, Perth Basin: WAM 71.138, depth unknown, Paulik's bore, Semple Rd, Jandakot (1 specimen); WAM 76.1588, 34.3 m, Paulik's bore, Semple Rd, Jandakot (1 specimen); WAM 77.1037, 31.5–32.2 m, Nu-Mix Concrete bore, Macglaglan St, Jandakot (1 specimen); WAM 77.3263, Adrian's Nursery bore, corner Thomas and Semple roads, Jandakot (1 specimen); WAM 78.3302, 27.1 m, Paulik's bore, Semple Rd, Jandakot (2 specimens).

Remarks. Although this is an uncommon species, the range of Recent material in AMS (66 lots) makes it clear that it is a single variable species, ranging from central coast of Western Australia (as far north as the Houtman Abrolhos; Wells & Bryce 1985: 158) all around southern Australia and Tasmania to Queensland and the Northern Territory (a most unusual distribution for an apparently endemic species that has not been reported more widely in the tropical Indo-West Pacific).

About 20% of specimens examined bear the 9–11 more prominent costae, or narrow plicae, characteristic of *Semipallium*, and some of these have been selected for illustration (Figs 18A–D, 21B) to show the resemblance to other fossil species in the genus. Even these plicate specimens have shagreen microsculpture all over. The tall, narrow, prosocline shape is also characteristic of *Semipallium*. The holotype of '*Notochlamys*' *hallae* Cotton, illustrated by Cotton (1960: unnumbered fig.; 1961: fig. 85; Lamprell & Whitehead 1992: pl. 12, fig. 71) agrees with this coarsely sculptured form of *S. aktinos* in most characters, although it is not quite as tall and narrow as most specimens and has still wider and more prominent plicae. *S. hallae* appears likely to be a synonym of *S. aktinos* or, perhaps, a closely related species of *Semipallium*.

A Recent juvenile specimen of *S. aktinos* from Western Australia was examined by SEM for comparison with the fossils (Fig. 21A, C–G). The LV preradial dissoconch microsculpture agrees almost exactly with that of *S. foulcheri* (Fig. 19B, D). Distinguishing characters of *S. aktinos* are its narrower umbonal angle, its longer and higher anterior auricle and shorter posterior auricle than those of *S. foulcheri* and, in particular, a unique narrow radial ridge produced on the crest of each major radial costa in *S. aktinos* by the shagreen microsculpture. Like the rest of the shagreen, this ridge is easily abraded away, and is not present on larger specimens examined.

Genus ***Serripecten*** Marwick, 1928

Serripecten Marwick, 1928: 455.

Type species (by original designation). *Pecten hutchinsoni* Hutton, 1873 (= *Pecten yahliensis* Tenison Woods, 1865), Miocene, Australia and New Zealand.

Remarks. Serripecten yahliensis (= *hutchinsoni*) is a large, spectacular pectinid, up to *c.* 170 mm long, markedly longer than high, with a wide umbonal angle and radial sculpture of low, serrate costae, much fewer, wider and more prominent on the RV than on the LV. All *Serripecten* species have rather uniform LV radial sculpture of numerous low, closely spaced, finely scaly costae, and although there are specific differences in the LV sculpture, they are very much less marked than the differences in RV sculpture. The beautifully preserved specimens from Fyansford Formation near Melbourne were studied by SEM (Fig. 24A–H), and show that the LV preradial dissoconch, like the rest of the shell surface, is sculptured with very fine, closely spaced antimarginal ridgelets. These form the sole sculpture on the LV preradial dissoconch, which therefore closely resembles that of *Zygochlamys delicatula* (Fig. 41C, E). Auricles are low and long and, although the RV anterior auricle is elongated, with a moderately deep byssal notch and a functional ctenolium in specimens of *S. yahliensis* up to about half-grown, ie., juveniles presumably are byssally attached, the byssal notch is very shallow in large adults. In most species, auricles are separated from the disc by quite prominent grooves.

In *S. yahliensis*, the RV radial sculpture is of relatively few low, wide costae (most specimens have *c.* 30–40; ranging from 26–50; Boreham 1965:

fig. 3). The few costae near the centre of the disc are of symmetrical section, but the others all have a sloping, bevelled section, with a low, wide, gentle slope facing towards the disc centre, a sharp crest, and a short, steeply sloping edge facing away from the disc centre. Many of the larger specimens have large, serrate spines along the steep edge of each costa, lying on the gently sloping face of the neighbouring costa. The RV dorsal margin of the auricles also bears large serrate spines.

However, *S. yahliensis* is one of the more unusual species of *Serripecten*. The numerous (many still unnamed) small Eocene and Oligocene species in New Zealand (eg., Maxwell 1992: pl. 4) have different sculpture, with many finely scaly costae on the RV, and the Australian *S. excultatus* sp. nov. is a finely sculptured example of this type. The Australian *S. squamocostatus* sp. nov. (known to us only from Longfordian rocks) resembles a rather large version of the New Zealand Eocene species, with quite similar scaly costae on both valves, recalling the species described by Maxwell (1992). The trend in the *S. yahliensis* lineage towards longer and lower auricles at a large size is carried still further by its apparent descendent, the huge *S. carteri* sp. nov. in Mitchellian rocks of Gippsland; this species has the auricles fused with the disc in large adults, and the radial sculpture develops numerous fine costellae not seen in *S. yahliensis*.

A final unexpected side branch of the evolutionary radiation of *Serripecten* is provided by *S. semilaevis* (McCoy) which, contrary to the coarsening RV sculpture trend seen in the evolution of *S. yahliensis*, has an almost completely smooth RV. Although it is concluded here that *S. yahliensis* is conspecific with the New Zealand *S. hutchinsoni*, so it is clear that there has been considerable trans-Tasman exchange of larvae in some *Serripecten* species, neither *S. carteri* nor *S. semilaevis* are known in New Zealand. These apparent absences are to be expected because the genus barely survived into the Late Miocene in New Zealand, and in Late Miocene rocks is recorded only from the Gisborne district in the northeastern North Island [Beu 1995: 75; three specimens of *S. yahliensis* recorded (as *S. hutchinsoni*) from the early Late Miocene Patutahi Limestone, near Gisborne]. Sea temperatures around much of New Zealand apparently were too low for *Serripecten* by Late Miocene time.

The one pectinid genus from elsewhere in the world that appears to be similar to *Serripecten* is *Batequeus* Squires & Demetrion, 1990, based on *Batequeus mezquitalensis* gen. nov., sp. nov. from Middle Eocene (Lutetian) rocks of Baja California Sur, Mexico. This species closely resembles the Eocene *Serripecten* species from New Zealand described by Maxwell (1992) in size, shape and sculpture, but the RV has a deeper byssal notch and a more depressed byssal fasciole and the RV exterior is sculptured with more prominent, more elevated, square-edged, more subdivided, markedly smoother radial costae than in any New Zealand or Australian *Serripecten* species. Campbell (1995) added a second species, *B. ducenticostatus*, from the Eocene Santee Limestone of South Carolina, commenting on the similarity to *Serripecten*. The frequently subdivided and intercalated costae, the smooth interior lacking internal rib carinae, and the narrow resilial and dorsal hinge teeth show that *Batequeus* belongs in the Chlamydini, and it appears to be quite feasible that it is closely related phylogenetically to *Serripecten*, although the similarity is, on present knowledge, as likely to be convergent.

Serripecten aldingensis (Tate, 1886)

Fig. 22A, B, D, E

Pecten aldingensis Tate, 1886: 109, pl. 7, fig. 1a–c.
Pecten williamsoni; Hutton, 1887: 482 (in part not *P. williamsoni* Zittel, 1864).
Pecten (Chlamys) aldingensis; Marwick, 1924: 325, pl. 6, fig. 14.

Description. Very small for genus (*c*. 25–32 mm high), slightly wider than high, moderately weakly inflated, RV slightly more inflated than LV; acline to very weakly prosocline; umbonal angle moderately wide (105–110°). Exterior sculpture of many (*c*. 60–68) low, wide, closely spaced radial costae with weakly convex crests, little-subdivided and more closely spaced on RV, more frequently subdivided and intercalated and with wider interspaces on LV; interspaces closely sculptured with low, relatively coarse antimarginal ridgelets; much of disc surface, particularly distal third to half, crossed by low, very thin, relatively widely spaced commarginal lamellae, weakly arcuate to shallowly V-shaped where they cross costae, more numerous and more frequently V-shaped on LV than on RV of most specimens. RV anterior auricle retaining moderately deep byssal notch and ctenolium in adults, upper auricle surface bearing 6–7 low, narrow, closely spaced radial costae; LV anterior auricle long, high, anterior margin weakly sinuous, sloping towards anterior; sculptured with 8–10 low, narrow, widely spaced radial costae bearing small, narrow scales; posterior auricles small, tall, inclined strongly towards anterior, sculptured as LV anterior auricle. Interior not seen.

Dimensions.

Lectotype, SAM T942A	H	28.2	L 27.7	LV
Figured paralectotype, SAM T942B		31.5	30.1	RV
Paralectotype, SAM T942D		31.1	32.1	RV
Paralectotype, SAM T942E		26.3	26.9	LV

Type material. Lectotype, here designated, Tate's (1886: pl. 7, fig. 1a) figured LV syntype, SAM T942A; paralectotypes, (1) Tate's (1886: pl. 7, fig. 1b) figured syntype RV, SAM T942B, (2) unfigured syntype, SAM T942D, and (3), unfigured syntype, SAM T942E, all from 'Glauconitic limestone, Aldinga Bay', near Adelaide, South Australia (= Tortachilla Limestone, Aldingan). The fifth unfigured paralectotype, SAM T942C, has narrower and more prominent radial costae than any specimens of *S. aldingensis* we have seen, and appears to be a juvenile specimen of *Talochlamys eyrei* (Tate).

Other material examined. **Aldingan:** TORTACHILLA LIMESTONE: Aldinga (10 specimens); WAM 94.189–191, Maslin Beach (5 specimens); PL3464, Maslin Beach (1 specimen); AMS C129230, Aldinga Bay (4 specimens); PALLINUP SILTSTONE: WAM 71.1026, 19 km S of Jerramongup, near Bremer River, WA (1 specimen, mould of exterior).

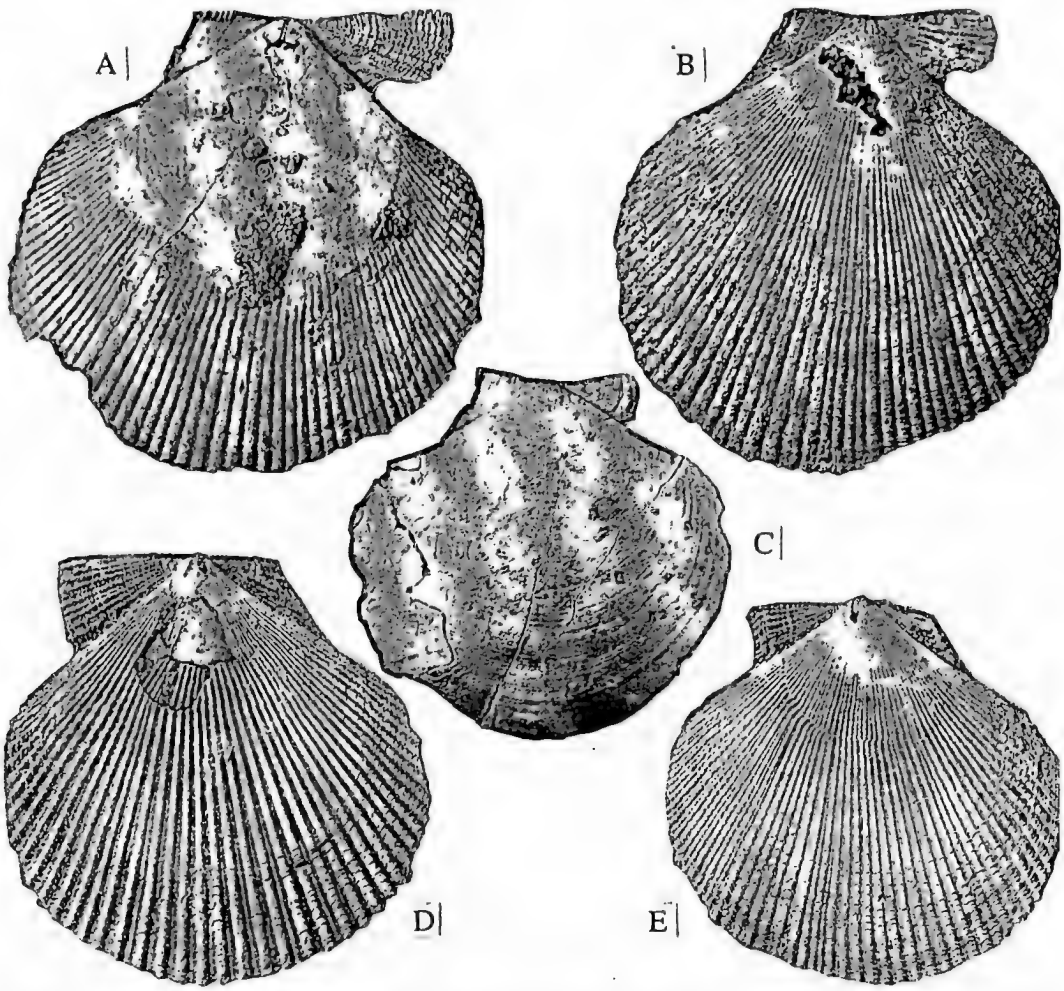


Fig. 22. A, B, D, E, *Serripecten aldingensis* (Tate), 4 of Tate's 7 syntypes, 'Eocene, Aldinga Bay', = Tortachilla Limestone (early Aldingan), coast SW of Adelaide; all enlarged, × 2: A, paralectotype, SAM T942D, unfigured RV; B, paralectotype, SAM T942B, figured RV; D, lectotype (designated here) of *Pecten aldingensis* Tate, SAM T942A, figured LV; E, paralectotype, SAM T942E, unfigured LV. C, *Serripecten* sp. nov., smooth Janjukian species; RV, P300051, PL3552, Clifton Formation, Kawarren lime pit, Victoria, at natural size.

Ludbrook (in Lowry 1970: fig. 21C) identified a specimen from Wilson Bluff Limestone at Abrakurrie Cave, Nullarbor Plain, as '*Chlamys*' *aldingensis*. The very fine, close, numerous radial costae of the specimen, as illustrated, make this identification feasible, but the specimen on examination at GSWA is immature, lacks the proximal third of the disc, and is indeterminable.

Occurrence and time range. Aldingan (Late Eocene); recorded with certainty only from the type locality and from Pallinup Siltstone in southern Western Australia.

Remarks. Because of its small size (to *c.* 32 mm high), its weak sculpture, and the large RV byssal notch retained in the largest specimens seen, it was far from clear at first that *S. aldingensis* really fitted comfortably into *Serripecten*. The material seen though, gives the appearance that the weakness of the sculpture on most specimens results from abrasion. The four largest syntypes of *Pecten aldingensis* are better-preserved than most other material we have seen, and show that unabraded specimens have thin commarginal lamellae over at least the ventral third of the disc on both valves, and LVs have much narrower costae and wider radial interspaces than RVs. LVs have interspaces about the same width as a costa, or only slightly narrower, have significantly more costal subdivision and intercalation than RVs, and have the intercostal spaces closely sculptured with the same relatively coarse antimarginal ridgelets as on RVs. The two syntype LVs also display much fine, scaly commarginal sculpture and, particularly towards the anterior end of the valve, the lamellae are strongly curved to V-shaped where they cross the costae, giving the sculpture a closely similar appearance to that of New Zealand Eocene *Serripecten* species. These characters indicate that a position in *Serripecten* is correct. However, the New Zealand Late Paleocene and/or Early Eocene species *S. tiorioriensis* Marwick (1928: 458, fig. 14) is larger (to *c.* 45 mm high), with more finely subdivided, narrower and more widely spaced, more obviously scaly radial costae, although the RV anterior auricle is very similar in the two species. The much younger *S. aldingensis* evidently is not closely related phylogenetically to *S. tiorioriensis*, but represents a separate lineage of small *Serripecten* species. All other *Serripecten* species we are aware of are larger and more coarsely sculptured than these two.

Serripecten excultatus sp. nov.

Fig. 23A–C

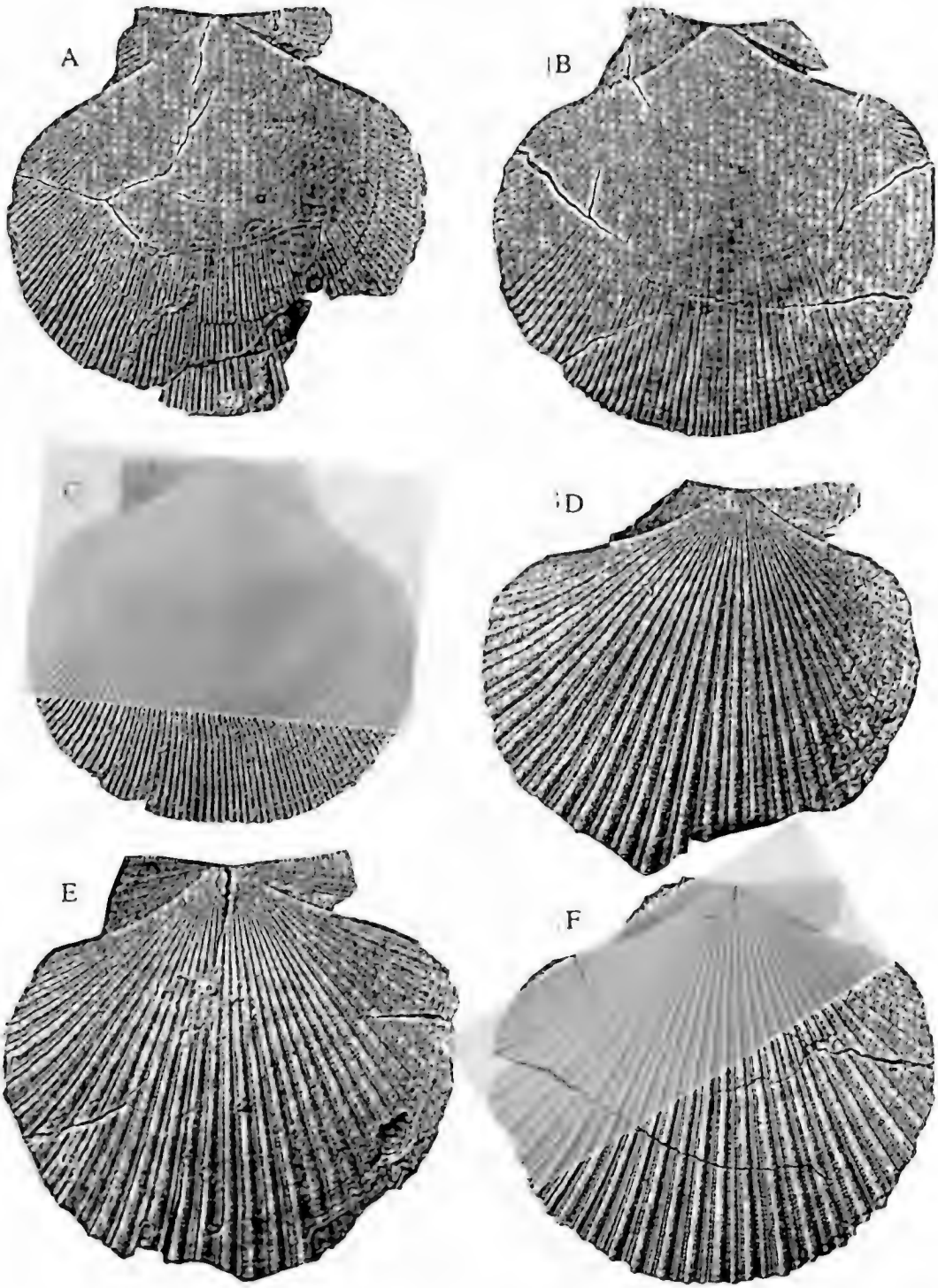
Description. Shell of moderate size for genus (to *c.* 70 mm high), polished and weakly sculptured, with inflation of both valves about equal. Umbonal angle 120–130°, increasing in larger specimens. RV polished, sculptured only with very faint radial striations over proximal third of disc, sculpture strengthening over central third of disc, until by distal third of disc of large specimens sculpture consists of *c.* 100–110 very low radial costae, with interspaces equal to or slightly wider than one costa, of symmetrical section and smooth-crested over most of disc, slightly more prominent, narrow-crested and inclined towards anterior near anterior end and towards posterior near posterior end, weakly and irregularly subdivided and intercalated to increase in number across disc, bearing very low, weak, closely spaced commarginal scales near ventral margin of some large specimens. LV similar to RV in being weakly sculptured over proximal third, developing weak but regularly increasing, obscure, smooth radial ridges over central third of disc, and sculptured with *c.* 110 low, wide, obscurely margined, closely spaced radial costellae over distal third of disc, differing from RV in having normal low, widely spaced commarginal lamellae of *Serripecten* over entire surface of distal half of disc. Posterior auricles of both valves significantly taller than anterior ones, with posterior margin nearly straight, inclined strongly towards anterior; RV anterior auricle with deep byssal notch, deeply depressed, narrow byssal fasciole and functional ctenolium in all specimens seen (ie., adults evidently byssally attached); RV auricle dorsal margins closely and finely serrate; LV anterior auricle with only very weakly sinuous, nearly vertical anterior margin; all auricles sculptured as on neighbouring disc. Interior without rib carinae. Hinge with low, narrow, but obvious dorsal and resilial teeth.

Dimensions.

Holotype, P302072	H 63.2	L 66.3	RV
Paratype, P302073, Browns Creek	61.8	63.1	RV
Paratype, P302074, Browns Creek	54.2	57.2	LV

Type material. Holotype, NMV P302072, Browns Creek Clay (Aldingan), PL3014, above dark gritty clay, at top of section in gully nearest mouth of Johanna River, Browns Creek, Johanna district, Victoria, grid ref. Glen Aire 079058; coll. T. A. Darragh, 12.xi.1984; 2 paratypes (one RV, one LV), NMV P302703–4, all data as holotype.

Other material examined. **Aldingan:** BROWNS CREEK CLAY: PL3014, type locality (9 specimens); PL3016, Castle Cove (14 specimens); WAM 94.618, type locality (32 specimens); AMS C135207, Castle Cove (2 specimens).


A
B
C
D
E
F

Occurrence and time range. Late Aldingan (late Eocene); restricted to the top of Browns Creek Clay at Browns Creek and the nearby Castle Cove, southern Victoria.

Remarks. *S. excultatus* sp. nov. differs from almost all the other Australian species of *Serripecten* by having very weak sculpture, with the proximal half of the disc of both valves polished and almost smooth, and sculpture developing gradually out across the rest of the disc. The sculpture on the anterior and posterior ends of the RV and on the distal part of the LV is similar to that of adult specimens of *S. aldingensis* but, as *S. aldingensis* is much smaller than *S. excultatus*, this shows that the sculpture of *S. excultatus* is much the finer. All other species have markedly coarser sculpture. *S. excultatus* superficially resembles the New Zealand Oligocene and Late Eocene species assigned to *Janupecten* Marwick, 1928 (ie., the real *Lentipecten*) and, although the RV sculpture of *S. excultatus* is similar to that of some '*Janupecten*' species, these all have an almost smooth LV, with only faint radial ridgelets developing near the ventral margin on a few specimens, and all lack the scaly, fine, closely spaced radial costellae of the LV of *Serripecten*.

Etymology. The specific name (Latin, '*excultus*', polished) refers to the external surface of the valves.

Serripecten sp. nov.

Fig. 22C

Remarks. We have seen very few specimens of *Serripecten* from Janjukian rocks, and a few of these seem to be typical *S. yahliensis* (Tenison Woods). Others seem to represent another, as yet unnamed species. The RV of this species is almost completely smooth, but has a few weak commarginal furrows, and in some specimens has a few low, faintly defined radial costellae on the anterodorsal and posterodorsal margins of the disc. The upper part of the RV anterior auricle, above the byssal fasciole, is sculptured with 4–5 low radial costae, and the auricles closely resemble those of *S. excultatus* sp. nov. The LV is sculptured much as in all other *Serripecten* species, although the few, small LVs seen seem to indicate that the sculpture is weaker than on most other species. The LV is only weakly inflated; the RV is strongly inflated, particularly in the umbonal area and centre of the disc; the disc margins are flattened compared with the umbo.

This species has a more inflated RV and a less inflated LV than *S. excultatus* sp. nov., and differs from it markedly in its thicker shell, and in its even more reduced radial sculpture on the RV. It seems likely to have evolved directly from *S. excultatus* sp. nov. by continuing the trend already seen in *S. excultatus* to lose radial sculpture on the RV. The large time gap between their ranges indicates that the unnamed Janjukian species had nothing to do with the origins of the markedly younger smooth species, *S. semilaevis*. Evolution of a smooth RV seems to have occurred twice in Australian *Serripecten* species, despite the fact that there is no record of smooth taxa in New Zealand. We have seen only about 10 specimens of the new species, and most are very small; it is desirable to see a larger range of material before naming the species.

Dimensions.

NMV P300051, PL3552	H 49.3	L 51.7	RV
NMV P300053, PL529	31.4	31.8	RV
NMV P302791, PL529	27.4	29.6	LV
NMV P59334, PL529	23.3	23.6	LV

Material examined. **Janjukian:** WAURN PONDS LIMESTONE: PL529, Waurn Ponds (7 specimens); CLIFTON FORMATION: PL3552, Kawarren (1 specimen); JAN JUC FORMATION: Ad22, Bird Rock, Torquay (2 specimens).

Occurrence and time range. Limited to Janjukian rocks, as far as we are aware. We have seen specimens only from Torquay, Kawarren and Waurn Ponds.

Fig. 23. A–C, *Serripecten excultatus* sp. nov., Browns Creek Clay (Aldingan), PL3014, top of section in gully nearest mouth of Johanna River, Browns Creek, coast W of Cape Otway, Victoria; all at natural size: A, paratype, RV, P302073; B, holotype, RV, P302072; C, paratype, LV, P302074. D–F, *Serripecten squamocostatus* sp. nov., Longfordian, all RVs, at natural size: D, holotype, P302082, PL3191, Mannum Formation, Klose Road, 400 m N of Mannum–Purnong Road, Murray River, South Australia; E, paratype, P302085, PL3231, Gambier Limestone, N of Donovans Road, *c.* 1 km SW of 'Summer Hill', near Donovans, South Australia; F, paratype, P302084, Gippsland Limestone, PL3251, Merrimans Creek Quarry, near Stradbroke West, Gippsland, Victoria.

Serripecten squamocostatus sp. nov.

Fig. 23D–F

Description. Moderate-sized for genus (to *c.* 70 mm high), RV moderately inflated, LV more weakly inflated than RV, length slightly to moderately greater than height; umbonal angle very wide, 130–140°; the most coarsely sculptured of Australian *Serripecten* species. RV sculptured with *c.* 33–37 relatively wide, moderately high primary radial costae of almost symmetrical, rounded section, narrower than on centre of disc and inclined slightly towards anterior near anterior end, narrower and inclined slightly towards posterior near posterior end, with interspaces each about twice width of one costa, bearing at least one narrow secondary costa in centre of each interspace, interspaces wider and bearing a few, irregular tertiary costellae on posterior fifth of disc of most specimens and on anterior fifth of some specimens; all crossed by low, regular, evenly spaced commarginal lamellae, up to *c.* 1 mm apart over centre of disc of large specimens, closer near anterior and posterior ends and towards ventral margin of large specimens, forming very low scales on costae. LV sculpture of *c.* 55–60 low, wide, primary radial costae, with interspaces about equal to or slightly wider than one costa, each interspace with one low, wide, central secondary costa arising early on disc and, in many specimens, rivalling or equalling primary costae in prominence by ventral margin; all crossed by thin, continuous, wavy commarginal lamellae, varying from slightly higher than on RV, forming low ventrally concave scales on costae, to 3–4 times height of RV lamellae, and thickened and elevated still further on costal crests to form thick, prominent, rather widely spaced, ventrally curved scales. RV anterior auricle with moderately deep, rather narrow byssal notch and weakly elevated byssal fasciole, ctenolial teeth present in narrow, shallow groove between auricle and disc on some specimens but apparently not functional in large specimens; byssal fasciole slightly raised above surface of neighbouring disc; flat upper area of auricle, above byssal fasciole, sculptured with 4–6 radial costae, as on disc, crossed by close, high, coarse commarginal lamellae; RV posterior auricle taller than anterior one, with strongly convex posterior margin, sculptured with narrow radial costae and thin lamellae as on neighbouring disc, separated from disc by moderately deep, undercut groove. LV anterior auricle moderately short, sculptured as on neighbouring disc, with anterior margin sloping slightly towards posterior, separated from disc by moderately deep, undercut groove; LV posterior auricle taller than anterior one, sculptured as on neighbouring disc, separated from disc by undercut groove as at anterior. Dorsal margins of RV auricles strongly but narrowly and sharply serrate. Interior smooth. Hinge with low, narrow but obvious dorsal teeth and short, low, obscure resilial teeth.

Dimensions.

Holotype, P302082, PL3191	H 59.8	L 65.4	RV
Paratype, P302085, PL3231	63.9	68.4	RV
Paratype, P302083, PL3196	66.1	70.8	LV
Paratype, P302081, PL3191	47.2	47.6	LV

Type material. Holotype, NMV P302082, Mannum Formation (Longfordian), PL3191, cutting on Klose Road, *c.* 400 m N of junction with Mannum–Purnong Road, 6 km NE of Mannum, South Australia, grid ref. Mannum 499395, coll. A. G. Beu & T. A. Darragh, 20.ix.1993; paratype, NMV P302081, all data as holotype; paratype, NMV P302083, Mannum Formation (Longfordian), PL3196, cliff at N end Big Bend Reserve, left bank Murray River, 7 km NNW of Nildottie, South Australia, grid ref. Swan Reach 727670, coll. A. G. Beu & T. A. Darragh, 22.ix.1993; paratype, NMV P302085, Gambier Limestone (here Longfordian), PL3231, quarry N of Donovans Road, *c.* 1 km SW of 'Summer Hill', 2.6 km west of Donovans, South Australia, grid ref. Gambier 937929, coll. A. G. Beu & T. A. Darragh, 9.xi.1993; NMV P302084, paratype, Gippsland Limestone (Longfordian), PL3251, Merrimans Creek quarry, nr Stradbroke West, Gippsland, grid ref. Stradbroke West 952652, coll. A. G. Beu & T. A. Darragh, 17.xi.1993.

Other material examined. **Longfordian:** MELTON LIMESTONE: PL3295, Myponie Pt (2 specimens); GAMBIER LIMESTONE: PL3231, quarry off Donovans Rd (4 specimens); GIPPSLAND LIMESTONE: PL3251, Merrimans Creek quarry (4 specimens); MANNUM FORMATION: PL3181, cutting near Reedy Creek (1 specimen); PL3186, cutting opposite Kia Marina (10 specimens); PL3191, cutting, Klose Rd, Mannum (13 specimens); PL3194, Walker Flat (3 specimens); PL3196, Big Bend Reserve (2 specimens); PL3212, Murray cliffs, 'Cave Cliff' (1 specimen); lower beds, Murray River cliffs, Overland Corner (1 specimen); Murray cliffs opposite centre of entrance to lagoon, Punyelroo (3 specimens); lower beds, Murray cliffs, Wongulla (6 specimens); lower beds, Murray cliffs, Wongulla to Mannum (8 specimens); Murray River cliffs, Nildottie (1 specimen); WAM 86.356, cliff E side Murray River, Ponde Rd, 1.9 km from turnoff from Mannum–Murray Bridge Rd (1 specimen).

Occurrence and time range. Apparently restricted to Longfordian. We have seen specimens only from Mannum Formation along the Murray River, from Gambier Limestone around Mount Gambier (where it is much less common than *S. yahliensis*), and from Gippsland Limestone at Merrimans Creek, near Stradbroke, Gippsland.

Remarks. *Serripecten squamocostatus* sp. nov. is similar in size to *S. excultatus* sp. nov., differing in having a much thicker shell and very much coarser sculpture. It is usually much smaller and, for its size, more coarsely sculptured than *S. yahliensis*, although specimens from Gambier Limestone are no smaller than the largest specimens of *S. yahliensis* from there. The more prominent, more widely spaced radial costae of narrower, rounded rather than wide, bevelled, narrowly crested section, without triangular scales, and with one to several consistent secondary and tertiary costellae, and the more prominent, more continuous commarginal lamellae distinguish the RV sculpture readily from that of *S. yahliensis*, and the wider, less numerous costae and much coarser scales distinguishes the LV from that of *S. yahliensis*. In fact, *S. squamocostatus* much more nearly resembles the New Zealand Eocene and Oligocene species of *Serripecten* (eg., those figured by Maxwell 1992: pl. 4) than it does *S. yahliensis*; it particularly resembles *S. tahuianus* Laws, 1935 and the unnamed LV figured by Maxwell (1992: pl. 4i) in sculptural details, but differs from these species in its markedly larger size, its slightly weaker sculpture, its more widely spaced costae on the RV (than in *S. tahuianus*; RV not known for the unnamed species) and in having much more finely and closely serrate RV dorsal auricular margins. It therefore seems likely that *S. squamocostatus* is descended from the New Zealand Eocene and Oligocene coarsely sculptured species.

Etymology. The specific name (Latin, '*squama*', a scale, +'*costatus*' ribbed) reflects the coarse scaly sculpture that is diagnostic of this species.

Serripecten yahliensis (Tenison Woods, 1865)

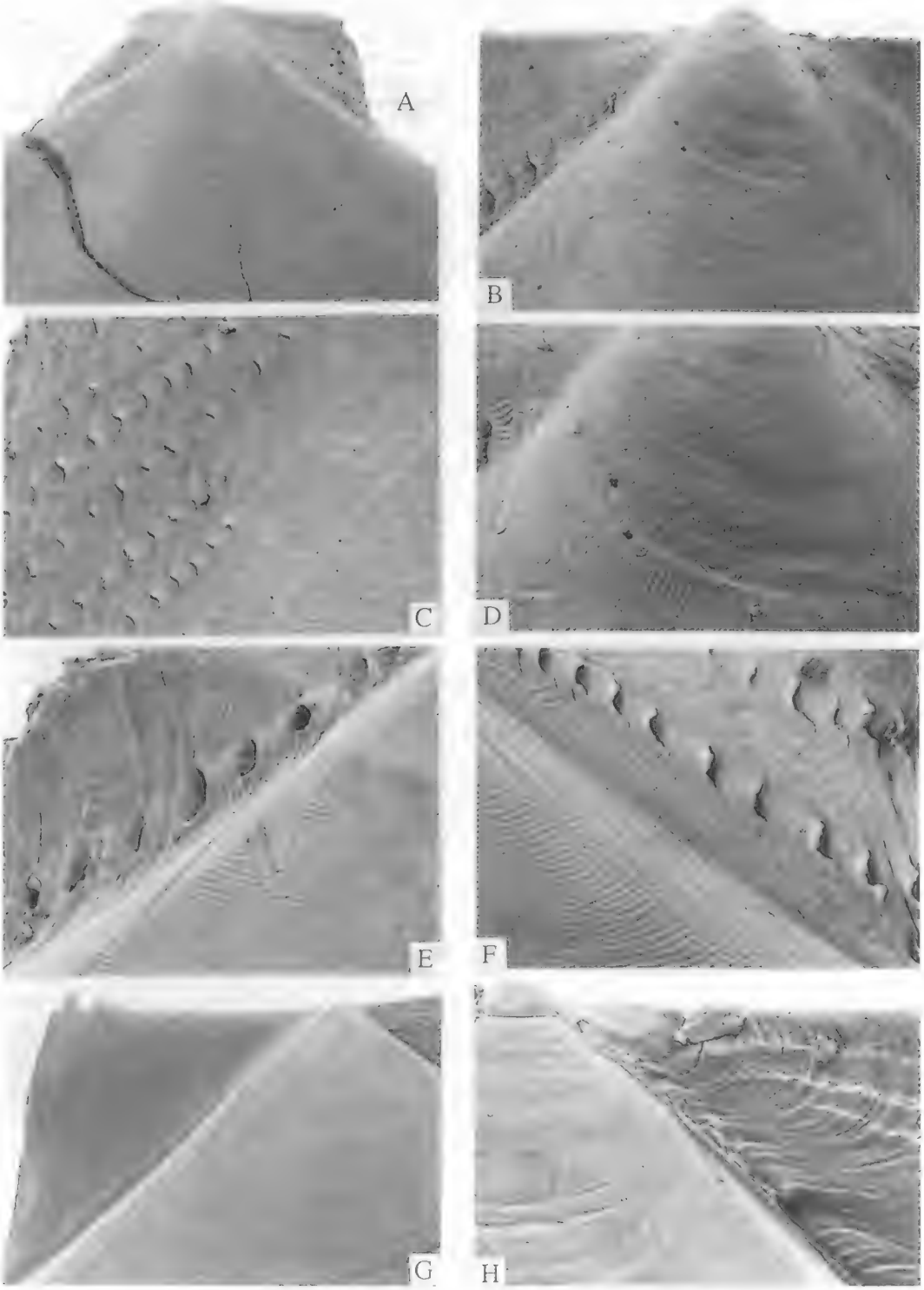
Figs 24A–H, 25A–D, 26E

Pecten yahliensis Tenison Woods, 1865: 1, fig. 4A, B.
Pecten hutchinsoni Hutton, 1873: 31; Hutton, 1887: 234.
Pecten beethami Hutton, 1873: 31; Hutton, 1887: 234; Harris, 1897: 319.
Pecten beethami var. B Hutton, 1873: 32; Suter, 1914: 41, pl. 8, fig. 1a, b.
Pecten yahlensis [*sic*]; Tate, 1886: 110; Tate & Dennant, 1893: 224; Pritchard, 1896: 127; Marwick, 1924: 326, pl. 6, fig. 10.
Pseudamussium yahlensis [*sic*]; Harris, 1897: 322.
Pecten (Patinopecten) beethami; Suter, 1914: 40, pl. 7, fig. 1.
Pecten (Patinopecten) hutchinsoni; Suter, 1914: 40, pl. 10, fig. 1.
Serripecten hutchinsoni; Marwick, 1928: 449, 455; Grindley et al., 1961: 102, pl. 4, fig. 3; Boreham, 1965: 28, pl. 8, figs 1, 2; pl. 9, figs 1, 2; Fleming, 1966: 21; Beu & Maxwell, 1990: 178, pl. 17f, g.
Serripecten beethami; Marwick, 1928: 449, 455.
Serripecten yahliensis; Crespin, 1950: 152, pl. 14, figs 14, 15.

Description. Very large (to 150 mm high, 170 mm wide), width markedly exceeding height in large specimens, small ones equidimensional; umbonal angle very wide (140–145°); RV much more inflated and much more coarsely sculptured than LV, which is conspicuously flattened near umbo on many specimens. RV exterior sculptured with *c.* 30–50 narrow radial costae (about 40 on many specimens), *c.* 4–6 near centre of disc symmetrical and of triangular section, with central keel and scales on crests, remainder bevelled, inclined towards disc ends, ie., anterior costae inclined towards anterior end and posterior costae inclined towards posterior end of disc, with short, almost vertical face towards ends and long, nearly smooth, gently inclined face towards disc centre, each costa margined by small to large, obvious, triangular scales lying on gently inclined face of neighbouring costa; some specimens have one or a few fine, inconspicuous secondary and tertiary costellae in interspaces. LV with up to three times as many costae that are much lower, narrower and more closely spaced than on RV, and rendered finely and evenly scaly by low, thin, sinuous, closely spaced commarginal lamellae over entire disc. Auricles low and very wide, almost symmetrical in large shells; RV anterior auricle retaining moderately deep byssal notch (with height about equal to depth) and functional ctenolium to more than half adult size (to *c.* 100 mm wide), byssal notch thereafter reduced, very shallow in large specimens; RV auricles with sculpture as on disc, dorsal margins coarsely and conspicuously scaly, with large triangular scales projecting vertically from commarginal growth ridges. LV auricles long, low, as in RV, sculptured as on LV disc. RV auricles separated from disc by deep, undercut grooves, not present in *S. carteri*. Interior weakly corrugated but without carinae. Hinge with low, narrow dorsal and resilial teeth only.

Dimensions.

Neotype of *S. yahliensis*			
NMV P302181	H 58.1	L 64.5	RV
NMV P300156, Corio Bay	91.4	95.7	RV
NMV P300135, Hospital Creek, Lakes Entrance	110.7	122.9	LV
NMV P300079, PL3524, Batesford	107.9	132.4	RV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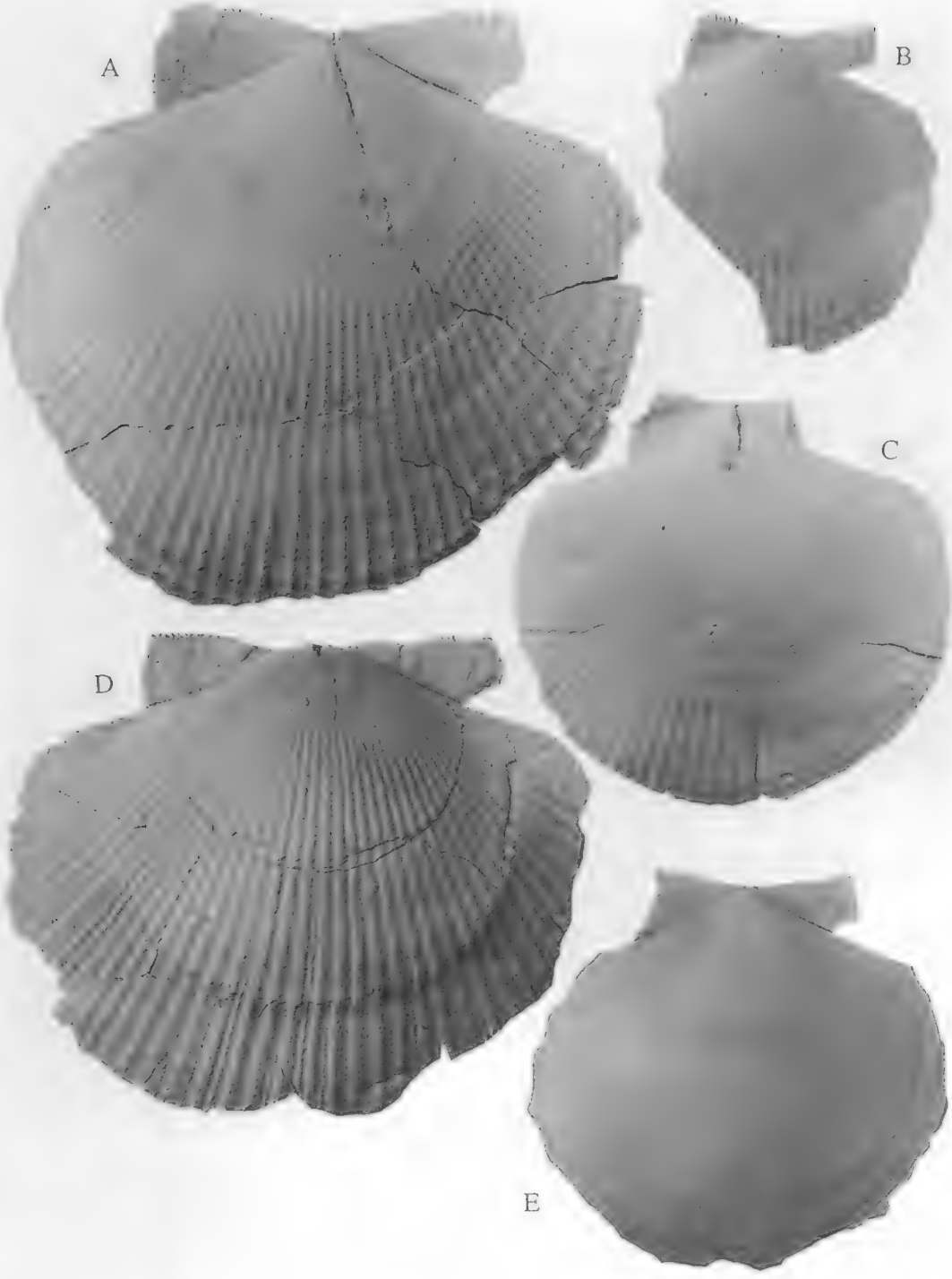
F
G
H

Type material. As noted under *Semipallium foulcheri*, Tenison Woods' type material cannot be located. His illustrated specimen came from 'a well close to Yahl' near Mt Gambier. In view of the fact that two *Serripecten* species are present in Gambier Limestone, we select a neotype to preserve the name in its accustomed sense. Neotype of *Pecten yahliensis* Tenison Woods, 1865, designated here, NMV P302181 (Fig. 25C), from Gambier Limestone (Longfordian), PL3244, council quarry on I. N. & C. J. Smith's property, 0.3 km west of Smith Road and 1.6 km south of Kingley Road, Port McDonnell, South Australia, grid ref. Schank 700923, coll. A. G. Beu & T. A. Darragh, 11.xi.1993; this almost complete RV is the cleanest and most complete specimen we collected from Gambier Limestone, although its auricles are incomplete; another specimen (NMV P302182; Fig. 25B) from the same locality with complete auricles is illustrated also to show the strongly serrate auricles characteristic of *S. yahliensis*. *Pecten hutchinsoni* Hutton, 1873, lectotype, IGNS TM2838, from 'Kaipuki', = Kaipuke cliffs, West Nelson coast between Anatori and Big rivers, northwestern South Island, Altonian (late Early Miocene) (Boreham 1965: 28); *Pecten beethami* Hutton, 1873, lectotype, IGNS TM2839, from 'Upoko Ngaruru', = Upokognaruru Stream, Wainuioru Valley, Wairarapa, east Wellington, Lillburnian–Waiauan (late Middle Miocene) (Boreham 1965: 28), with one paralectotype, specimen identified as *Pecten beethami* var. B by Hutton (1873), IGNS TM2840, from 'Oamaru', exact locality unknown, but probably from Devil's Bridge, in Gee Greensand, Otaian (Early Miocene).

Other material examined. **Longfordian:** FOSSIL BLUFF SANDSTONE: Turritella bed, Table Cape (11 specimens); AMS F14291, Table Cape (1 specimen); GAMBIER LIMESTONE: railway quarry 12 km NNW of Mt Gambier (2 specimens); PL3219, quarry, Nelson North Rd (4 specimens); PL3220, Glenelg River, Nelson (3 specimens); PL3221, Glenelg River cliff at Donovans (3 specimens); PL3222, quarry NNW of mouth of Dry Creek (14 specimens); PL3223, quarry, Border Rd (5 specimens); PL3224, quarry N of Dry Creek Valley (33 specimens); PL3225, quarry between Bonds and Dry Creek rds (9 specimens); PL3228, Glenelg River cliff (2 specimens); PL3231, Donovan's Rd quarry (64 specimens); PL3233, Tervorft Rd quarry (34 specimens); PL3236, pit on McLeans Rd (3 specimens); PL3241, Telford's fish farm (7 specimens); PL3242, quarry, Telford's fish farm (5 specimens); PL3244, quarry, Smith's property, Port MacDonell (5 specimens); Glenelg River cliff opposite mouth of Dry Creek (5 specimens); allot. 2, Parish of Roseneath, Victoria (1 specimen); GIPPSLAND LIMESTONE: PL3250, Calcimo Quarry (12 specimens); PL3251, Merrimans Creek quarry (54 specimens); PL3254, Boggy Creek quarry (3 specimens); PL3255, Darriman Quarry (4 specimens); Longford (5 specimens); MANNUM FORMATION: PL3180, Sunnyside Lookout (1 specimen); PL3195, Swan Reach, SA (1 specimen); PL3196, Big Bend Reserve (1 specimen); PL3199, Murray cliffs, 'Cooinda' (6 specimens); PL3212, Murray cliffs, 'Cave Cliff' (13 specimens); Murray River cliff opposite centre of entrance to lagoon, Punyelroo (3 specimens); lower beds, Murray cliffs at Overland Corner (2 specimens); lower beds, Murray River cliffs at Wongulla (2 specimens); lower beds, Murray River cliffs, Wongulla to Mannum (9 specimens); AMS F5892, F5894, cliff 76, Swan Reach, Parish of Nildottie, SA (2 specimens); NARACOORTE LIMESTONE: PL3245, Comaum Forest quarry (14 specimens); PL3246, Elderslee Quarry (25 specimens); PL3247, James Quarry (4 specimens); AMS C122943, C124106, Naracoorte (4 specimens); PUEBLA FORMATION: Polyzoal limestone, beach N of Bird Rock, Torquay (3 specimens); cliff between Spring Creek and Torquay (1 specimen); limestone between Jan Juc and Bird Rock, Torquay (1 specimen); SANDFORD LIMESTONE: Jackson's Bluff, Glenelg River (1 specimen); ZEALLY LIMESTONE: Jan Juc Point, at mouth of Spring Creek, Torquay (1 specimen). **Batesfordian:** BATESFORD LIMESTONE: 3 m from bottom, far end of tunnel, new quarry, Batesford (1 specimen); GLENELG GROUP: Greenwald landslip (1 specimen); FYANSFORD FORMATION: PL3041, Fc20, Yarrowee River (5 specimens); PL3039, GSV Ad12, Curlewis (3 specimens); WUK WUK MARL: PL3054, Skinners (1 specimen). **Balcombian:** FYANSFORD FORMATION: PL3095, GSV Ad15, Corio Bay (17 specimens); Carrum sewerage tunnel (1 specimen); lower beds, Grices Creek (3 specimens); AMS C74895, Fossil Beach, Balcombe Bay (3 specimens); GELLIBRAND FORMATION: 1.6–2.5 km E of Glenample Steps, Princetown (1 specimen); MORGAN LIMESTONE: PL3197, Greenways Landing (1 specimen); lower beds, Murray River, between Pelican Point and Blanchetown (1 specimen); MUDDY CREEK FORMATION: PL3082, Clifton Bank, Muddy Creek (102 specimens). **Bairnsdalian:** BAIRNSDALE LIMESTONE: PL3105, Pleasant Creek (2 specimen); PL3174, Nelson Bros. Quarry (32 specimens); PL3276, Devil's Backbone, Lochend (8 specimens); Bairnsdale (3 specimens); E bank Lake Tyers, cliff 6.4 km below Nowa Nowa (12 specimens); Reedy Arm, Lake Tyers (1 specimen); Princes Highway cutting, Toorloo Arm, Lake Tyers (2 specimens); Princes Highway cutting, Hospital Creek (2 specimens); cutting on new deviation, N side Hospital Creek bridge (1 specimen); pit on Johnson's farm, W bank Hospital Creek (1 specimen); Nowa Nowa Arm, Lake Tyers (1 specimen); N side Orbost railway line, drainage excavation nr Simpsons Creek (1 specimen); FYANSFORD FORMATION:

Fig. 24. Serripecten yahliensis (Tenison Woods), type species of *Serripecten* Marwick, 1928, SEMs of juvenile LV (H 22.6 mm) (A–F) and RV (H 22.4 mm) (G, H) of one specimen, P300414, Fyansford Formation (Bairnsdalian), 'middle beds' at Grice's Creek, Mt Eliza, Victoria. Enlargements of umbonal area and incomplete auricles (A × 4), sculpture of preradial dissoconch (B × 16, D × 32), showing simple antimarginal ridgelets typical of Chlamydini; development of the frilled radial costae (C × 12, E, F × 16); and umbonal area and smooth posterior auricle of RV (G × 9) and deep byssal notch and functional ctenolium (H × 50).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PL3102, Warrambine Creek (2 specimens); PL3104, Manyung Rocks (24 specimens); PL3100, Murgheboluc 4A (11 specimens); PL3101, North Shore, Corio Bay (25 specimens); junction Native Hut Creek and Barwon River, Inverleigh (1 specimen); AMS C70704, Grices Creek, Mt Eliza (6 specimens); middle beds, Grices Creek (21 specimens); PL3095, Western Beach, Corio Bay (7 specimens); Corio Bay (3 specimens); PORT CAMPBELL LIMESTONE: PL3093, Rutledge Beach (1 specimen); PL3094, Ingle Creek (1 specimen); bottom of Gibson Steps; Princetown (7 specimens); BOOKPURNONG FORMATION: PL3133, Wookool Bend, near Loxton (11 specimens).

Occurrence and time range. In Australia, Longfordian to Bairnsdalian, from the Murray to Gippsland Basins. Replaced in the Mitchellian Tambo River Formation in Gippsland by *S. carteri* sp. nov., so the incomplete, abraded specimens from Black Rock Sandstone (Cheltenhamian) at Beaumaris are referred to *S. carteri* rather than *S. yahliensis*. *S. yahliensis* occurs with *S. semilaevis* in Bookpurnong Formation at Wookool Bend, near Loxton, indicating either that (a) Bookpurnong Formation is Bairnsdalian, or (b) *S. yahliensis* survived later in Murray Basin than in Gippsland Basin; the first alternative seems much the more likely to us given the presence of other Middle Miocene taxa in Bookpurnong Formation.

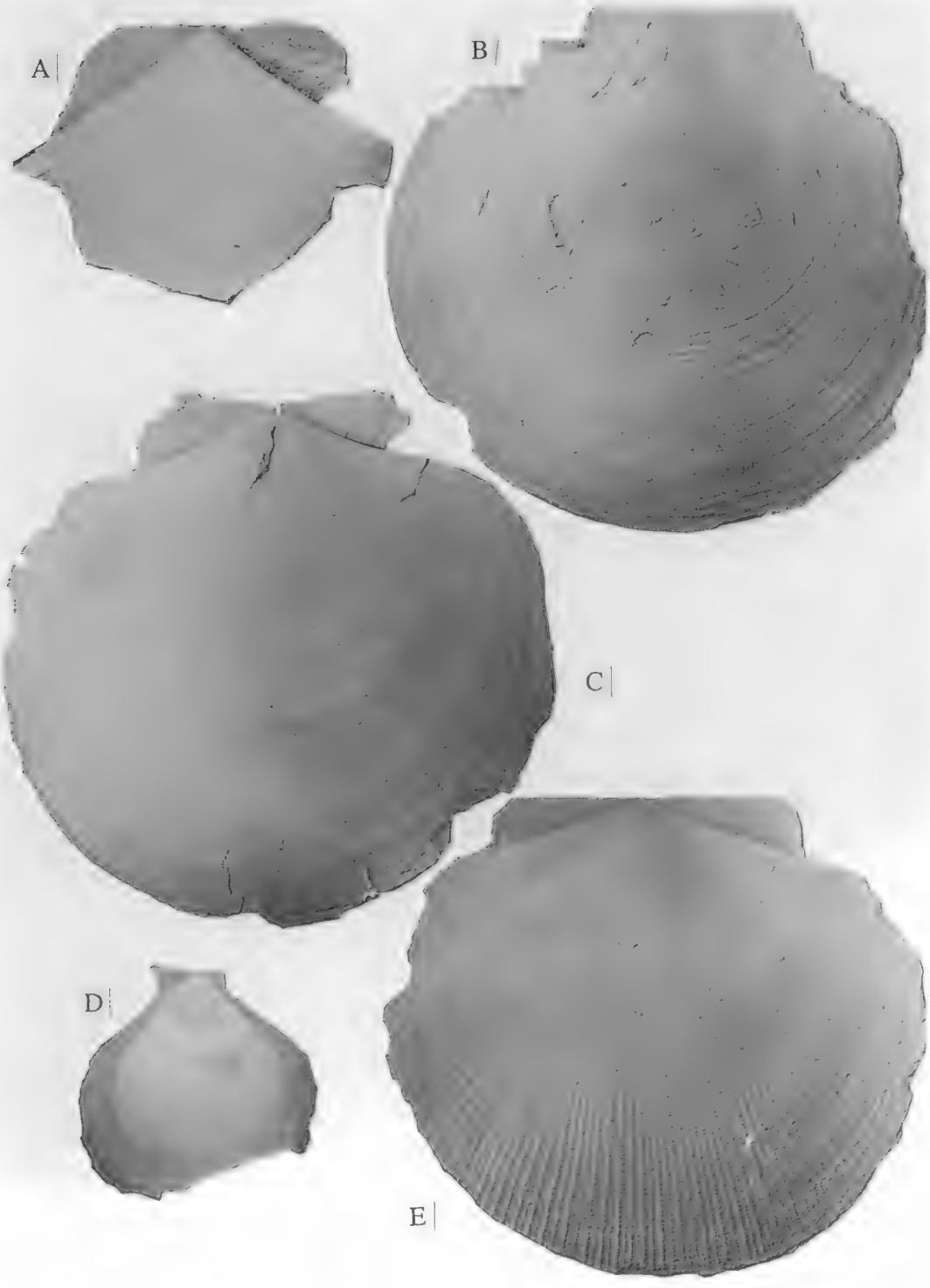
In New Zealand, *Serripecten yahliensis* occurs widely throughout the two main islands, in rocks of Otaian to Waiauan age (Early to late Middle Miocene), and several specimens are known from the Tongaporutuan (early Late Miocene) Patutahi Limestone at Gisborne, northeastern North Island. Boreham (1965: 30) regarded the earliest occurrence as Duntroonian (Late Oligocene), but this was probably based on the unnamed ancestral species. The time range therefore is close to that in Australia.

Remarks. This highly distinctive scallop is easily recognised by its large size, and by being shaped and sculptured very much as in *S. carteri* but with auricles set off from the disc by deeper grooves, and with many fewer secondary costellae and little or nothing in the way of tertiary costellae. Many specimens from shallow-water limestone and shell-bed lithologies have very coarsely serrate sculpture, with spine-like scales along the anterior edges of anterior costae and along the posterior edge of posterior costae, but this sculpture varies greatly in coarseness. The very coarsely scaly form was named *Pecten beethami* by Hutton (1873) in New Zealand, but Hutton's types were reviewed by Boreham (1965), who synonymised the *beethami* form with *S. hutchinsoni*. Many specimens of this large, coarsely sculptured form have a single, prominent secondary costa in most or all radial interspaces.

This is one of only three species of Cenozoic fossil mollusc, other than the widely dispersed species of the gastropod superfamily Tonnoidea [including *Cabestana tabulata* (Menke), *C. spengleri* (Perry), *Charonia lampas* (Linné), *Ranella australasia* (Perry), *Cymatium exaratum* (Reeve), *C. parthenopeum* (von Salis Marschlins), *Sassia tortirostris* (Tate), *S. parkinsonia* (Perry), *Semicassis pyrum* (Lamarck), and *S. labiata* (Perry)], that we are reasonably satisfied is common to Australia and New Zealand. The other two species in common are the Late Eocene species *Rugobela humerosa* (Marwick) (Turridae) and *Pseudomalaxis asculpturatus* Maxwell (Architectonicidae) (Beu & Maxwell 1990: 114). There are several problems about the type locality and age of *S. yahliensis* and some reservations as to whether all the Australian specimens we include here are really conspecific, but at least some specimens of this large Early and Middle Miocene species from Australia and New Zealand are indistinguishable, and a large range of variation in size and sculpture is seen in both regions. It seems reasonable to conclude that the forms on the two sides of the Tasman Sea are conspecific.

Tenison Woods (1865) stated that the holotype of *Pecten yahliensis* 'was got for me in sinking a well close to Yahl, Mount Gambier'. The place-name Yahl (pronounced 'yawl') is applied to a small area a few kilometres southeast of the present town of Mount Gambier, and unfortunately this is one of the few areas around Mount Gambier where there are now no exposures of Gambier Limestone.

Fig. 25. A–D, *Serripecten yahliensis* (Tenison Woods), all RVs: A, P300156, Fyansford Formation (Bairnsdalian), Corio Bay, Geelong, Victoria, at natural size; B, P302182, specimen from same locality as neotype (Fig. 25C), with complete auricles, at natural size; C, neotype of *Pecten yahliensis* Tenison Woods, P302181, Gambier Limestone (Longfordian), PL3244, council quarry 300 m W of Smith Road and 1.6 km S of Kingsley Road, Port McDonnell, South Australia, at natural size; D, P300079, Batesford Limestone (Batesfordian), Batesford, near Geelong, Victoria; typical large adult indistinguishable from New Zealand specimens identified as *S. hutchinsoni* (Hutton); reduced to × 0.67. E, *Serripecten semilaevis* (McCoy), RV with complete auricles, P302077, Wuk Wuk Marl (Bairnsdalian), PL3108, Driers, Mitchell River, W of Bairnsdale, Gippsland, Victoria; at natural size.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Quarries in other parts of the district have numerous specimens of *Serripecten*, however, and we take the more common of the species in these quarries to be *S. yahliensis*, particularly as Tenison Woods'. (1865: pl. 1, fig. 4A, B) figure clearly shows a shell indistinguishable in all but size from the common form of *S. hutchinsoni* in New Zealand; the size was 'length 2.8, breadth 3 inches', ie., about 71 mm high and 76 mm long. A map of age distribution of Gambier Limestone between Mount Gambier, in southeasternmost South Australia, and Nelson, in adjacent Victoria, provided by C. Abele (n.d.; 'Biostratigraphic and structure map of the Mt Gambier area'; unpub.), based on foraminiferal biostratigraphy, shows that most localities are Longfordian in age, including those along the Glenelg River near Nelson, whereas a few to the south, near Port McDonnell on the coast, are Batesfordian. As in New Zealand, all records are Miocene. In New Zealand, the 'typical' large form of *S. yahliensis*, up to 170 mm long, occurs in Early to Middle and, rarely, Late Miocene rocks (Otaian to Waiauan and, rarely, Tongaporutuan Stages) and a smaller, rather more coarsely sculptured species, apparently ancestral to *S. yahliensis*, occurs in Late Oligocene and, probably, basal Miocene rocks (Duntroonian and Waitakian stages) (Beu & Maxwell 1990: 178). Almost all the specimens we collected in the Mount Gambier district are small (not over about 80 mm long) and it seemed possible at first that they represent the putative smaller ancestor of *S. yahliensis* in New Zealand. However, all specimens from the Mount Gambier area are sculptured as in large, 'typical' *S. yahliensis*, and the NMV collection includes a single large specimen of *S. yahliensis*, closely resembling New Zealand ones, collected on the east bank of the Glenelg River by F. S. Colliver, from Gambier Limestone dated as Longfordian on Abele's map. Other Longfordian and Batesfordian specimens from Victoria and South Australia (in NMV and SAM) also reach the large size of New Zealand Miocene specimens. It appears that some environmental factor may have maintained most specimens from around Mount Gambier at a relatively small size. The second species that occurs with *S. yahliensis* in the quarry north of Donovan's Road, 2.6 km west of Donovan's, South Australia (where *Serripecten* occurs most commonly) is *S. squamocostatus* sp. nov.

Serripecten semilaevis (McCoy, 1876)

Figs 25E, 26A–D, 27A, B

Pecten yahliensis var. *semilaevis* McCoy, 1876: 13, pl.34.
Pecten yahlensis [*sic*]; Tate, 1886: 110 (in part not *Pecten yahliensis* var. *semilaevis* McCoy, 1876).
Amusium hochstetteri; Woods, 1931: 150 (not *Pecten hochstetteri* Zittel, 1864; *fide* Ludbrook, 1955: 32).
Lentipecten adelaidensis Ludbrook, 1955: 32, pl. 1, fig. 13a–c.

Description. Moderately large (to *c.* 100 mm wide and 90 mm high); umbonal angle very wide (*c.* 145°); length markedly exceeding height; easily recognised by RV being moderately inflated and nearly smooth, contrasting strongly with weakly inflated to almost flat LV, with fine, close, scaly radial sculpture similar to that of other *Serripecten* species. RV exterior smooth except for weak commarginal growth ridges and very faint, irregular radial threads and grooves at moderately wide intervals; LV exterior with fine, close, scaly radial costae, weaker than in other *Serripecten* species and a little polished on crests, but not easily distinguished from that of *S. yahliensis* when only LVs are compared. Posterior auricles very wide, taller than anterior ones (ie., posterodorsal margin more steeply inclined than anterodorsal one); RV anterior auricle retaining shallow but obvious byssal notch in adult, area above byssal fasciole sculptured with 4–6 low, narrow radial costae; RV posterior auricle smooth except for obvious commarginal growth ridges, posterior margin convex, inclined weakly towards anterior; dorsal margins of both auricles prominently serrate, with many short, close spines much smaller than those of *S. yahliensis*. LV auricles simple, with anterior and posterior margins inclined in towards umbo, sculptured as on disc. Hinge weak, as in *S. yahliensis*; with long, narrow dorsal teeth and short, thin resilial teeth diverging at more marked angle than in *S. yahliensis*.

Fig. 26. A–D, *Serripecten semilaevis* (McCoy), Bairnsdalian, South Australia: A, D, type material of *Lentipecten adelaidensis* Ludbrook; lower Dry Creek Sands, Abattoirs Bore, Adelaide; A, figured incomplete paratype RV, SAM F15121B, enlarged, × 3; D, holotype, juvenile incomplete RV, SAM F15121A, enlarged, × 3; B, C, two valves of one specimen, P300215, from PL3133, Bookpurnong Formation, Wookool Bend, near Loxton, Murray River, at natural size; B, LV; C, RV. E, *Serripecten yahliensis* (Tenison Woods), LV, P300135, from Bairnsdale Limestone (Bairnsdalian), cutting on Princes Highway at Hospital Creek, Gippsland, Victoria; reduced to × 0.67.

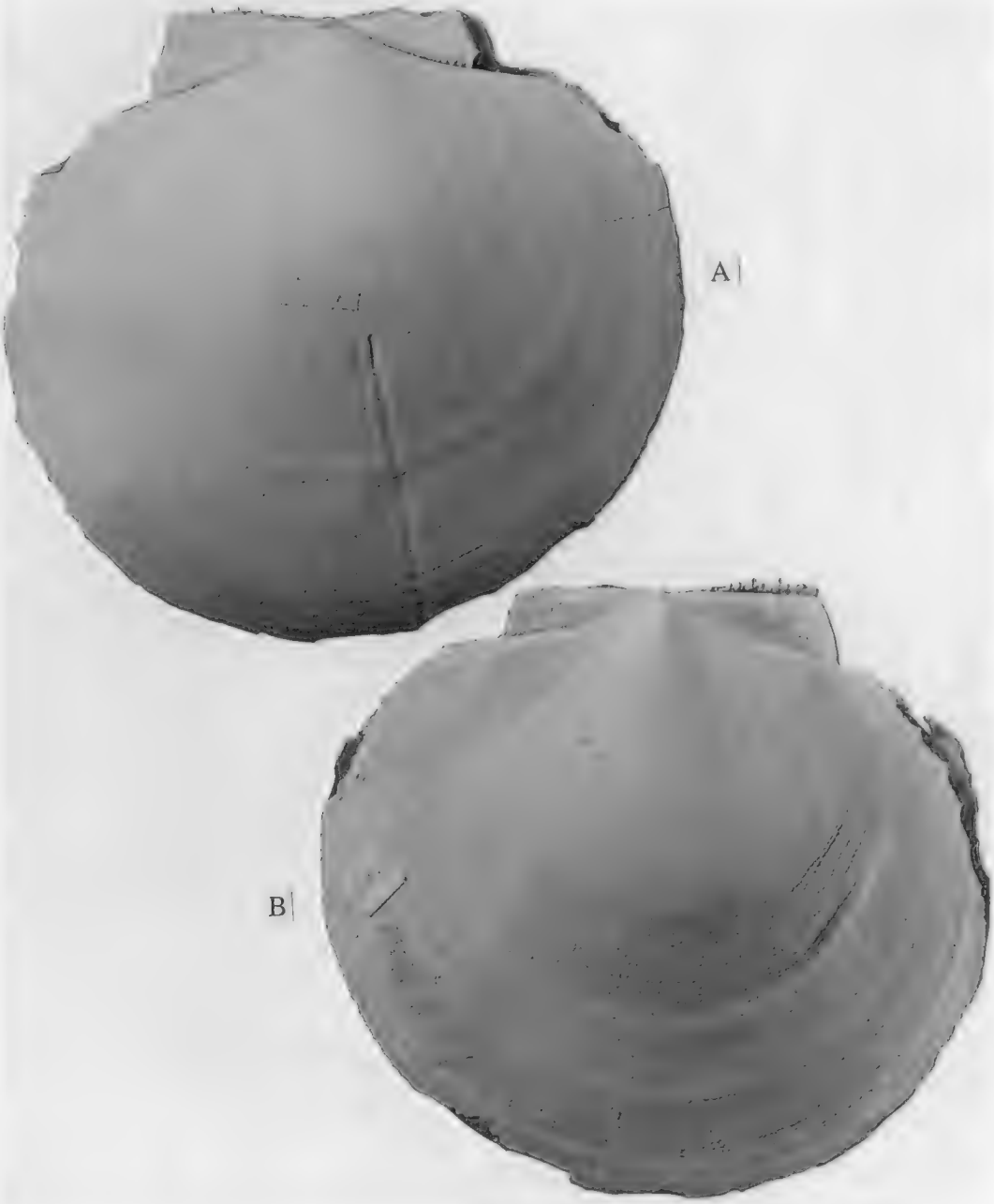


Fig. 27. *Serripecten semilaevis* (McCoy), holotype of *Pecten yahliensis semilaevis* McCoy, P12175, from Bairnsdale Limestone (Bairnsdalian), Mitchell River, Bairnsdale, Gippsland, Victoria; at natural size; A, RV; B, LV.

Dimensions.

Holotype, *P. yahliensis* var. *semilaevis* McCoy	H 89.2	L 95.7	2 valves
Holotype, *Lentipecten adelaidensis* Ludbrook	12.0	11.3	RV
P302077, PL3108	60.1	63.2	RV
P300215, PL3133	81.6	84.5	RV
same specimen as above	78.7	81.2	LV

Type material. Holotype of *Pecten yahliensis* var. *semilaevis* McCoy, 1876, NMV P12175 (Fig. 27A, B), from Bairnsdale Limestone (Bairnsdalian), Mitchell River, Bairnsdale, Gippsland, coll. A. W. Howitt; holotype of *Lentipecten adelaidensis* Ludbrook, 1955, SAM F15121 (Fig. 26D), from Dry Creek Sands (here Bairnsdalian), Abattoirs Bore, Adelaide; with 2 paratypes, both fragmentary RVs, same locality.

Other material examined. **Balcombian:** MUDDY CREEK FORMATION: PL3082, Clifton Bank (6 specimens); FYANSFORD FORMATION: Carrum sewerage tunnel (1 specimen). **Bairnsdalian:** BAIRNSDALE LIMESTONE: PL3107, McCraes Quarry (16 specimens); PL3108, Driers (7 specimens); PL3174, Nelson Bros. quarry (52 specimens); PL3175, Camerons Arm No. 2 track (36 specimens); PL3256, Myrtle Point (1 specimen); PL3257, Schaeche's Flat (4 specimens); PL3258, Dooley St lime pit (6 specimens); PL3276, Devil's Backbone, Lochend (2 specimens); Bairnsdale (13 specimens); Pound Reserve, Bairnsdale (1 specimen); Mitchell River cliff opposite Bairnsdale (5 specimens); Tambo River (3 specimens); road cutting at Upper Tambo (1 specimen); highway cutting E of Toorloo Arm (4 specimens); Princes Highway cutting at Toorloo Arm (2 specimens); Allot. 4, section B, Parish of Wy Yung, Myrtle Point, Bairnsdale (1 specimen); WAM 85.760, upper Tambo River, 8 km N of Swan Reach (1 specimen); PORT CAMPBELL LIMESTONE: PL3093, Rutledges (14 specimens); PL3094, Ingle Creek (25 specimens); coast towards Gellibrand, Sherbrooke River (6 specimens); mouth of Sherbrooke River (3 specimens); Gibsons Steps, 0.4 km W of Princetown (2 specimens); type section of Peterborough Lst, 5 km E of Peterborough (1 specimen); Point Hesse, W of Port Campbell (4 specimens); Loch Ard Gorge, near Port Campbell (1 specimen); 15–18 m below ground level, Curdies River (1 specimen); 3 m below top of cliff, Bay of Islands, Peterborough (1 specimen); base of cliff, Bay of Islands, Peterborough (2 specimens); 0.4 km inland from coast, Bay of Islands, Peterborough (1 specimen); gully 1 km W of the Grotto, W of Port Campbell (4 specimens); near Port Fairy (1 specimen); WUK WUK MARL: PL3108, Driers (10 specimens); windmill shaft, Mitchell River terrace at Rose Hill (5 specimens); BOOKPURNONG FORMATION: PL3133, Wookool Bend (28 specimens, incl. 2 articulated pairs); Murray River cliff at Marook 475934 (1 specimen); DRY CREEK SANDS: PL3299, Abattoirs Bore (2 specimens); PL3598, Waterloo Corner bore (10 specimens); PL3611, Royal Adelaide Golf course bore (1 specimen). **Cheltenhamian:** GOODWOOD FORMATION: PL3132, Spring Creek, Minhamite (4 specimens); BLACK ROCK SANDSTONE: Nodule bed, Beaumaris (3 specimens); Cheltenham (3 specimens).

Occurrence and time range. Balcombian to Cheltenhamian; almost all material is Bairnsdalian. Abundant in Rutledge's Creek Member of Port Campbell Limestone, Otway Basin, and in Bairnsdale Limestone, Gippsland Basin. The oldest specimens we have seen are a few from Muddy Creek Formation, Otway Basin, but this is the only Balcombian record. Specimens are common also in Bookpurnong Formation, Murray Basin. There are no records from the Mitchellian or younger rocks of Gippsland Basin.

Remarks. Serripecten semilaevis is the most distinctive and the most abundant Australian species of *Serripecten* although, not surprisingly, there has been much confusion both in the literature and on museum labels over the smooth RV and whether or not it belongs with the sculptured LV. The many specimens available to us with the two valves articulated leave no doubt that McCoy's holotype is no 'freak' specimen, but represents a species of great biostratigraphic utility, virtually limited to Bairnsdalian rocks. Obviously, the most distinctive character of the species is the lack of radial sculpture on the RV. The LV, in contrast, bears the usual *Serripecten* LV sculpture of many (*c.* 110–120) very low, closely spaced, finely scaly radial costae, although on *S. semilaevis* the sculpture is lower and considerably finer than on the other *Serripecten* species, and on many specimens the costal crests have a lightly polished appearance. *S. semilaevis* shares with *S. yahliensis* the RV being considerably more inflated than the LV, and the very wide umbonal angle (commencing at *c.* 105°, increasing as the shell grows to *c.* 145°), and the wide, low auricles. The auricles are demarcated from the disc by only shallow grooves, shallower than in *S. yahliensis*. These grooves are shallow on the RV, in particular and, as in *S. carteri*, the slightly swollen byssal fasciole protrudes a little above the neighbouring disc surface on some specimens. Both grooves are very shallow but obvious on the LV.

Ludbrook (1955: 32) considered that she had both RV and LV of a smooth species in her type material of *Lentipecten adelaidensis*, but her very small, smooth specimens are all more or less incomplete RVs. Many partially complete, smooth RVs and many quite large fragments of scaly-sculptured LVs have been seen among subsequently collected bore material from beneath Adelaide, and we can discern no characters that distinguish them from *Serripecten semilaevis*. In our opinion, *Lentipecten adelaidensis* Ludbrook was based on limited fragmentary material referable to *Serripecten semilaevis*.

A
B

Serripecten carteri sp. nov.

Fig. 28A, B

Description. Very large (to *c.* 150 mm high and 180 mm long), larger specimens markedly longer than high, smaller ones less obviously so; RV significantly more inflated than LV. Umbonal angle extremely wide (to 145–150° in large specimens); angle of posterior margin below hinge line significantly greater than anterior angle, ie., posterior auricle a little taller than anterior auricle. RV disc sculptured with *c.* 46–52 primary radial costae, similar to bevelled costae of *S. yahliensis* in general appearance (ie., with steep face towards anterior or posterior ends of shell, gentle slope towards centre of disc) but gentle slope towards centre more concave, producing a wide, almost flat intercostal space that bears 3–6 low, narrow, sharply defined costellae, with central costella raised into a narrow, well defined median costa in some interspaces; serrate scaly sculpture of steep anterior faces of anterior costae and posterior faces of posterior costae much finer and less obvious than in *S. yahliensis*. LV disc sculptured with *c.* 85–120 low, narrow radial costae, more clearly defined than on RV, with several fine secondary and tertiary costellae in interspaces, all crossed by numerous low, thin, closely spaced commarginal lamellae that form low scales on costal crests. Auricles extremely long and low, hinge length up to 60% of disc length (auricles 100 mm long on disc 168 mm long in holotype), anterior auricle of large specimens with very shallow remnant of byssal notch in RV and shallowly sinusoidal anterior margin in LV, posterior margin of both posterior auricles nearly vertical, lightly convex in outline; RV auricles separated from disc by shallow groove only, byssal fasciole of anterior auricle raised above neighbouring disc surface; LV auricles separated from disc by moderately deep, wide groove in small to moderately large specimens, becoming shallower with growth to form only moderately shallow groove in large shells. Ctenolium not functional in adult, remaining as a clearly visible row of teeth in groove between auricle and disc for about half shell height, or slightly greater, to point where byssal notch shallows markedly. Posterior auricles of both valves and LV anterior auricle sculptured as on neighbouring disc, RV anterior auricle very weakly sculptured, with low radial costae proximally but little sculpture distally. Dorsal margins of RV auricles finely and closely to moderately coarsely serrate. Interior surface smooth. Hinge with very long, narrow, prominent dorsal teeth and sockets, but low, rather inconspicuous resilial teeth and sockets.

Dimensions.

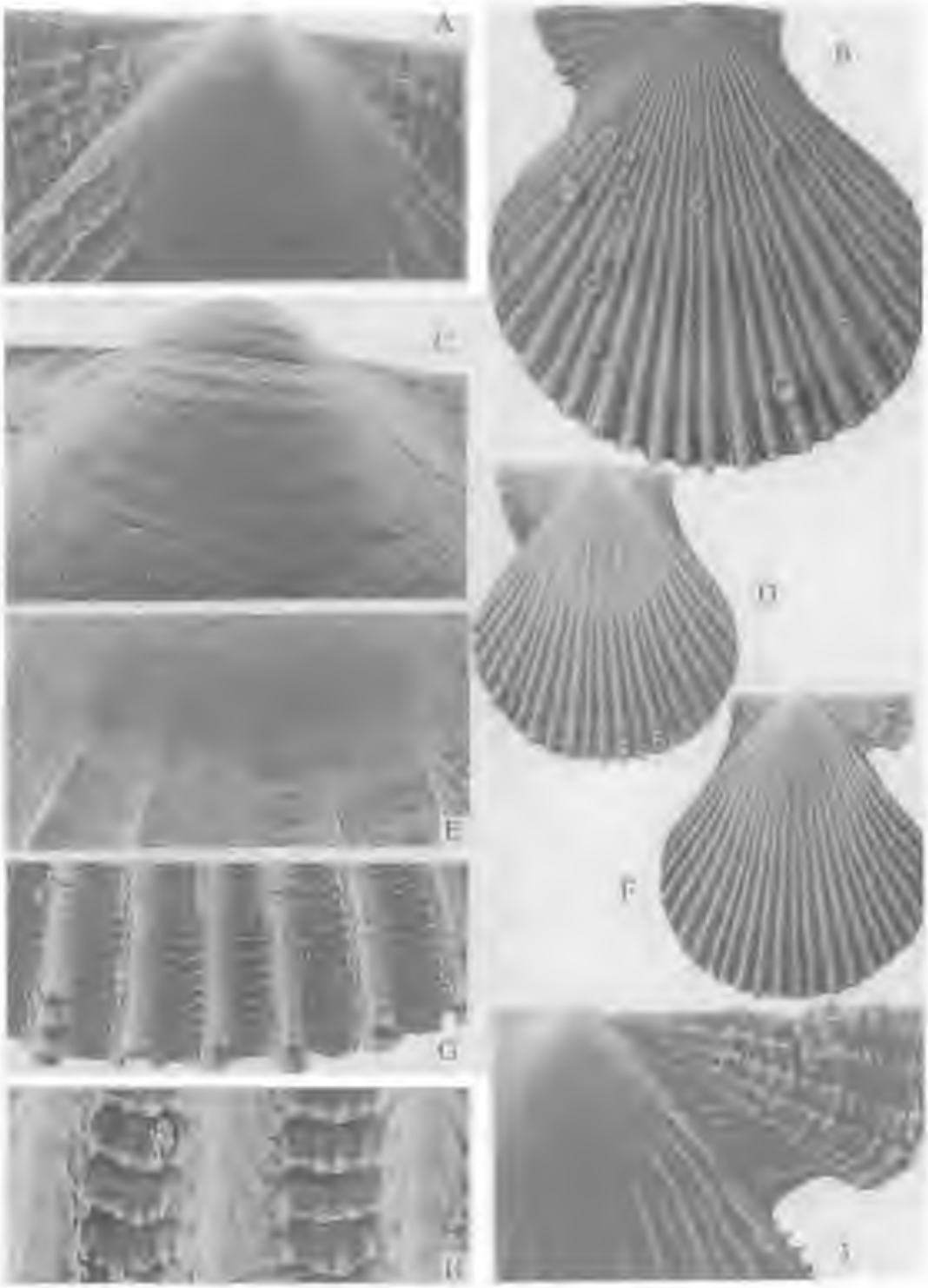
Holotype, P300116	H 142.8	L 167.9	RV
Paratype, P302214, PL3267	134.1	150.7	RV
Paratype, P302215, PL3267	116.9	127.1	RV
Paratype, P300122, PL3110	130.6	146.9	LV

Type material. Holotype, NMV P300116, Tambo River Formation (Mitchellian), PL3110, road cutting on Swan Reach–Metung Road, left bank of Tambo River, 200 m south of Princes Highway, Swan Reach, Lakes Entrance, Gippsland, Victoria, grid ref. Bairnsdale 759132, coll. F. A. Cudmore, 1939; paratype, NMV P300122, same data as holotype, don. University of Melbourne, 1989; 2 paratypes, NMV P302214–5, Tambo River Formation (Mitchellian), PL3267, low outcrop on shore of Reedy Arm peninsula, Nowa Nowa Arm, Lake Tyers, Lakes Entrance, Gippsland, grid ref. Orbost 994159, coll. A. N. Carter.

Other material examined. **Mitchellian:** TAMBO RIVER FORMATION: PL3110, Swan Reach cutting (9 specimens); PL3267, Reedy Arm peninsula, Lake Tyers (33 specimens); Nowa Nowa Arm, Lake Tyers (1 specimen). **Cheltenhamian:** BLACK ROCK SANDSTONE: Beaumaris (9 specimens); Cheltenham (3 specimens) (all referred tentatively).

Occurrence and time range. Apparently restricted to Tambo River Formation in the Gippsland Basin; uncommon at the type locality and abundant in the low outcrop on the Nowa Nowa Arm, Lake Tyers. The few large *Serripecten* specimens (ie., as distinct from *S. semilaevis*) from Beaumaris, near Melbourne (type Cheltenhamian) are too poorly preserved to determine whether they are *S. carteri* or *S. yahliensis*, although it seems likely that they are *S. carteri*, and we refer them there tentatively. It appears likely that *S. carteri* sp. nov. is a Mitchellian (and presumably Cheltenhamian) descendent of *S. yahliensis*, and it may have some utility in Gippsland biostratigraphy.

Fig. 28. Serripecten carteri sp. nov., Tambo River Formation (Mitchellian), Gippsland, Victoria, RVs, reduced to × 0.67. A, holotype, P300116, from PL3110, cutting on Swan Reach–Metung Road 200 m S of Princes Highway, Swan Reach. B, paratype, P302214, from PL3267, Reedy Arm peninsula, Nowa Nowa Arm, Lake Tyers, collected by Alan Carter.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Remarks. *Serripecten carteri* sp. nov. reaches an even larger size than its apparent immediate ancestor, *S. yahliensis*, and is very similar to it in shape and in general appearance. It differs from *S. yahliensis* in almost losing the byssal notch in large specimens, with only a shallow sinus remaining, in having the auricles almost completely fused with the disc surface on the RV and separated by only a shallow groove on the LV, so that the slightly swollen byssal fasciole of large specimens protrudes above the disc surface (in strong contrast to the deep, undercut grooves demarcating the auricles in *S. yahliensis*) and, most obviously, in having wider and more obvious radial interspaces that bear numerous fine secondary and tertiary costellae that are not present, or are represented by only an occasional single thread in most interspaces and several in a few interspaces, in *S. yahliensis*. The serrate sculpture and serrate dorsal margin are also much less prominent on *S. carteri* than on *S. yahliensis*. As with *S. squamocostatus* sp. nov., the LV is little different from that of *S. yahliensis*, except for its shallower grooves between the disc and the auricles, and we have not felt it necessary to illustrate the LVs of these species. The new species cannot be confused with any other species of *Serripecten*, all of which are much smaller.

Etymology. We have great pleasure in naming the new species in honour of the late Alan N. Carter, formerly of the University of New South Wales and the Geological Survey of Victoria, to record his long interest in the stratigraphy and foraminiferal biostratigraphy of Gippsland, as well as his great interest in scallops (eg., see Carter 1966). Alan was the first to collect at many of the localities we report here around Lake Tyers (see under *Mesopeplum meringae*), including the locality with common *Serripecten carteri*, and we have utilised his collections (now in NMV) in this work.

Genus ***Talochlamys*** Iredale, 1929

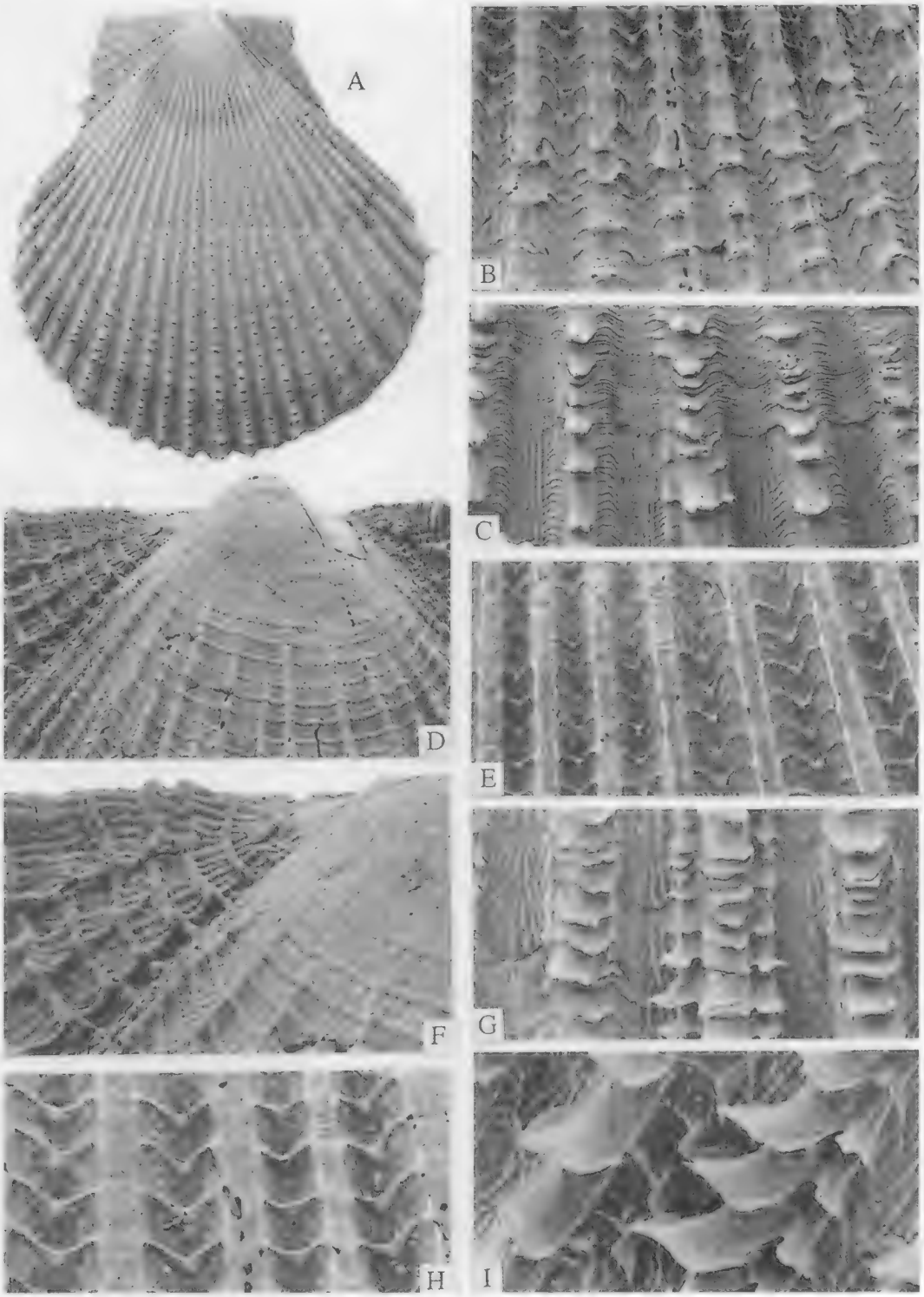
Talochlamys Iredale, 1929a: 164.

Type species (by original designation, Iredale 1929a: 188). *Chlamys famigerator* Iredale, 1925 (= *Pecten pulleineanus* Tate, 1887b: 73, pl. 4, fig. 1a, b), Recent, southern and eastern Australia.

Remarks. Beu (1995: 17) used *Talochlamys* for the New Zealand species *Chlamys dichroa* (Suter), *C. gemmulata* (Reeve) and *C. zelandiae* (Gray). SEM examination (Beu 1995: figs 3, 4) demonstrated that these taxa have LV preradial dissoconch sculpture of relatively coarse, prominent, antimarginal ridgelets and commarginal ridges, leaving a series of quite obvious, commarginally arranged, antimarginally directed, elongate pits between the raised sculptural elements. Since then, we have examined the type species, *T. pulleineana*, in the same way (Fig. 29A, C, E), and found it to have very much weaker sculpture on the LV preradial dissoconch than on the New Zealand species, essentially just commarginal rows of shallow, elongate, antimarginally directed pits. At first sight this sculpture seems dramatically different from that of such coarsely sculptured species as *T. dichroa*, but the differences are really ones of degree; the weak LV preradial sculpture on *T. pulleineana* appears to be what would result if the prominent sculpture of *T. dichroa* was abraded almost completely away. As differences of precisely this type are demonstrated elsewhere in this paper within apparent evolutionary series within one genus, we conclude that this sculptural difference alone is not a character distinguishing genera. Examples are *Semipallium*, the *Talochlamys keiloriana* species group, *Veprichlamys*, and *Mimachlamys*, in all of which species with coarser LV preradial sculpture seem to have evolved into species with weaker sculpture.

Comparison of other characters of these four species demonstrated that they share, also, commarginal lamellae in the radial interspaces that are frilled to varying degrees by the antimarginal ridgelets, which continue across the entire shell; low, wide, ventrally cupped to narrow, ventrally directed scales on costal crests; the retention of the byssally attached habit and its consequent chlamydoid shell form throughout life; and a number of primitive chlamydinine characters

Fig. 29. *Talochlamys pulleineana* (Tate), type species of *Talochlamys* Iredale, 1929, Recent. A, C–I, juvenile, SEM enlargements of sculpture, LV (A, C, D, E, G, H) and RV (F, I) of one specimen, AMS C305943, off Bermagui, New South Wales, MV 'San Pedro Sound', BMR Sta. 1756: D, F, whole shell, × 12; A, C, E, sculpture of preradial dissoconch enlarged (A × 40, C × 165, E × 80); G, sculpture of disc near ventral margin, × 55; H, sculpture enlarged further, × 150; I, RV anterior auricle and byssal notch enlarged, × 40. B, adult LV, AMS C305942, FIS 'Endeavour' Sta. E6184, 150 m S of Cape Everard, Bass Strait; enlarged, × 1.5.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including costal subdivision and intercalation, the absence of internal rib carinae, and the presence of only weak dorsal and resilial hinge teeth. From these considerations, it therefore seems reasonable to include all these species in a rather broadly defined, southern, primitive chlamydinine genus *Talochlamys*.

Australian Cenozoic fossil species related to '*Chlamys*' *keiloriana* Crespin share with *T. pulleineana* the very weak pitted sculpture of the LV preradial dissoconch, weak disc inflation, a relatively low, wide shape with a wide umbonal angle, and sculpture of relatively wide, well elevated costae bearing ventrally cupped or hooked scales. Another Australian fossil, the Eocene to Early Miocene '*Chlamys*' *eyrei* (Tate), shares gross morphological and sculptural characters with *T. pulleineana* and is included provisionally in *Talochlamys*, although we know little about its LV preradial dissoconch sculpture (see Fig. 31E, G). *T. eyrei* has shagreen microsculpture on a few specimens after inception of radial sculpture, a primitive chlamydinine character we have not seen on other *Talochlamys* species. However, evolutionary trends in other primitive chlamydinine genera include the presence of shagreen microsculpture on early species and its loss with time (eg., shagreen is present on South American early fossil *Zygochlamys* species, but not on Pliocene to Recent ones; T. R. Waller 1995, pers. comm.) and the presence of shagreen on *T. eyrei* in our view does not necessarily imply that it belongs in a genus distinct from *Talochlamys*.

As noted above under *Dichotochlamys dichotomalis*, that genus shares many significant characters with *Talochlamys*, and seems to have evolved from it by the acquisition of plicae, of large spines on the RV dorsal margin, and of a regular, relatively delayed (compared with that in *Talochlamys*) progression of costal subdivision down the disc.

Beu (1995: 17) pointed out that Iredale's (1925: 252, pl. 41, figs 1, 2) 'holotype' of *Chlamys famigerator* (= *T. pulleineana*) is actually two dissociated valves, and designated the LV the lectotype (AMS C53767).

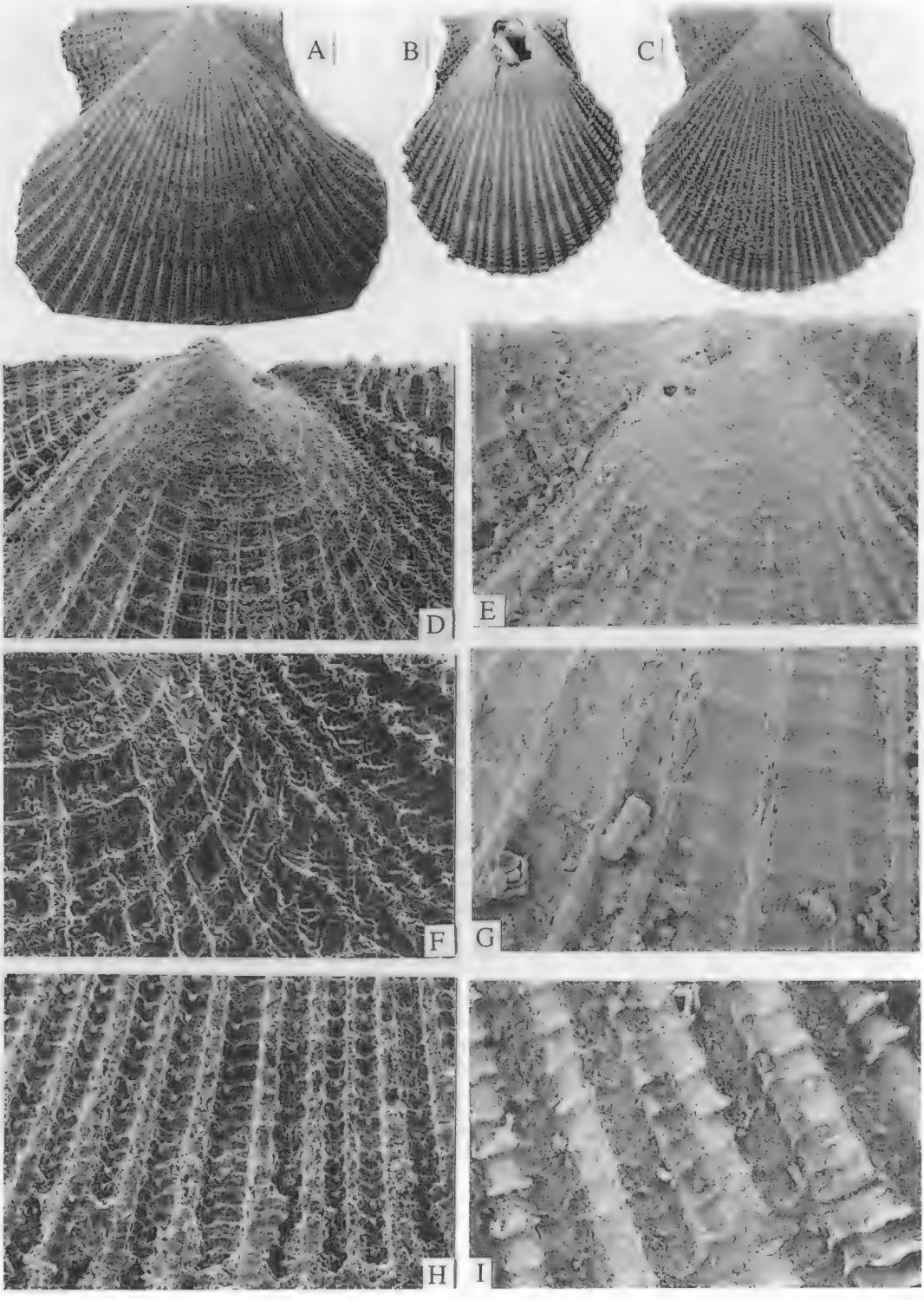
Talochlamys badioriva sp. nov.

Figs 30A–I, 31A, D, F, H, 32A–C

Pecten peroni Tate, 1886: 108 [in part; unfigured paralectotypes from Adelaide (= Kent Town) Bore only].

Description. Moderate-sized for genus (to *c.* 35 mm high), slightly taller than long (when small) to slightly longer than tall, umbonal angle 105–110° in adults; RV slightly more inflated than LV; acline to weakly prosocline. LV preradial dissoconch sculptured with antimarginal ridgelets and low but obvious commarginal ridges, forming tessellate sculpture and shallow, elongate pits more prominent than in *T. pulleineana* but less so than in *T. dichroa*. Disc sculpture of 26–32 moderately narrow, well elevated radial costae with rounded crests; most specimens developing narrow secondary costa on each side of each primary costa, commencing at valve height of 10–12 mm, to produce regular pattern of weakly fasciculate costae on distal half of disc of large specimens, although some costae remain undivided on others; some secondary costae subdivide more strongly to become separate narrow costae in intercostal space; low, narrow tertiary costellae intercalated in centre of radial interspaces at half valve height to near ventral margin of some large specimens, one costella in most interspaces of most specimens but up to 3 in some interspaces. Much or all of shell surface sculptured with fine antimarginal ridgelets, which are subdivided into groups of short, weakly radiating ridgelets between commarginal growth ridges over distal area of disc that bears subdivided primary costae. Commarginal ridges over proximal area of radially sculptured disc (after costal inception but before costal subdivision) raised into thin lamellae of shallow V-shape with edges of V lightly concave ventrally; after costal subdivision lamellae become lower or disappear on floor of interspaces, but become elevated into high, thin, ventrally concave but outward-curved scales, with separate longer, wider scales on primary costae and shorter, much narrower ones on secondary costae. RV anterior

Fig. 30. Talochlamys badioriva sp. nov., paratypes, 2 LVs, SEM enlargements of sculpture; Browns Creek Clay (Aldingan), 10 m below greensand bed, Brown's Creek, Johanna, coast west of Cape Otway, Victoria. A–D, F, H, P304574: A, whole shell, enlarged, × 4 (H 17.1 mm); D, F, sculpture of preradial dissoconch (D × 27, F × 55); B, H, sculpture of mid-disc, showing V-shaped commarginal ridges passing into antimarginal ridgelets (B × 33, H × 55; C, sculpture at ventral margin, with radial costae beginning to subdivide, × 25. E, G, I, P304575, sculpture at mid-disc and at ventral margin, showing long, ventrally concave but outward-curved scales on radial costae (E × 33, G × 50, I × 90).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auricle with very deep, moderately narrow byssal notch, functional ctenolium with 4–6 narrow teeth, depressed, strongly ridged byssal fasciole, and main auricular surface above byssal fasciole sculptured with 5–6 prominent, very scaly costae; LV anterior auricle tall, anterior margin lightly convex and inclined strongly towards anterior, sculptured with 6–7 narrow, finely scaly costae; posterior auricles short, with concave posterior outline, sculptured with 3–5 narrow, widely spaced, finely scaly costae; dorsal margins of RV auricles strongly serrate. Interior smooth apart from weakly notched ventral margin. Hinge with long, low, thin dorsal teeth and short, very narrow resilial teeth beside dorsal half of resilifer.

Dimensions.

Holotype, NMV P301355	H 29.5	L 30.4	RV
	27.7	28.8	LV
Paratype, NMV P301513, Browns Creek	33.3	33.6	RV

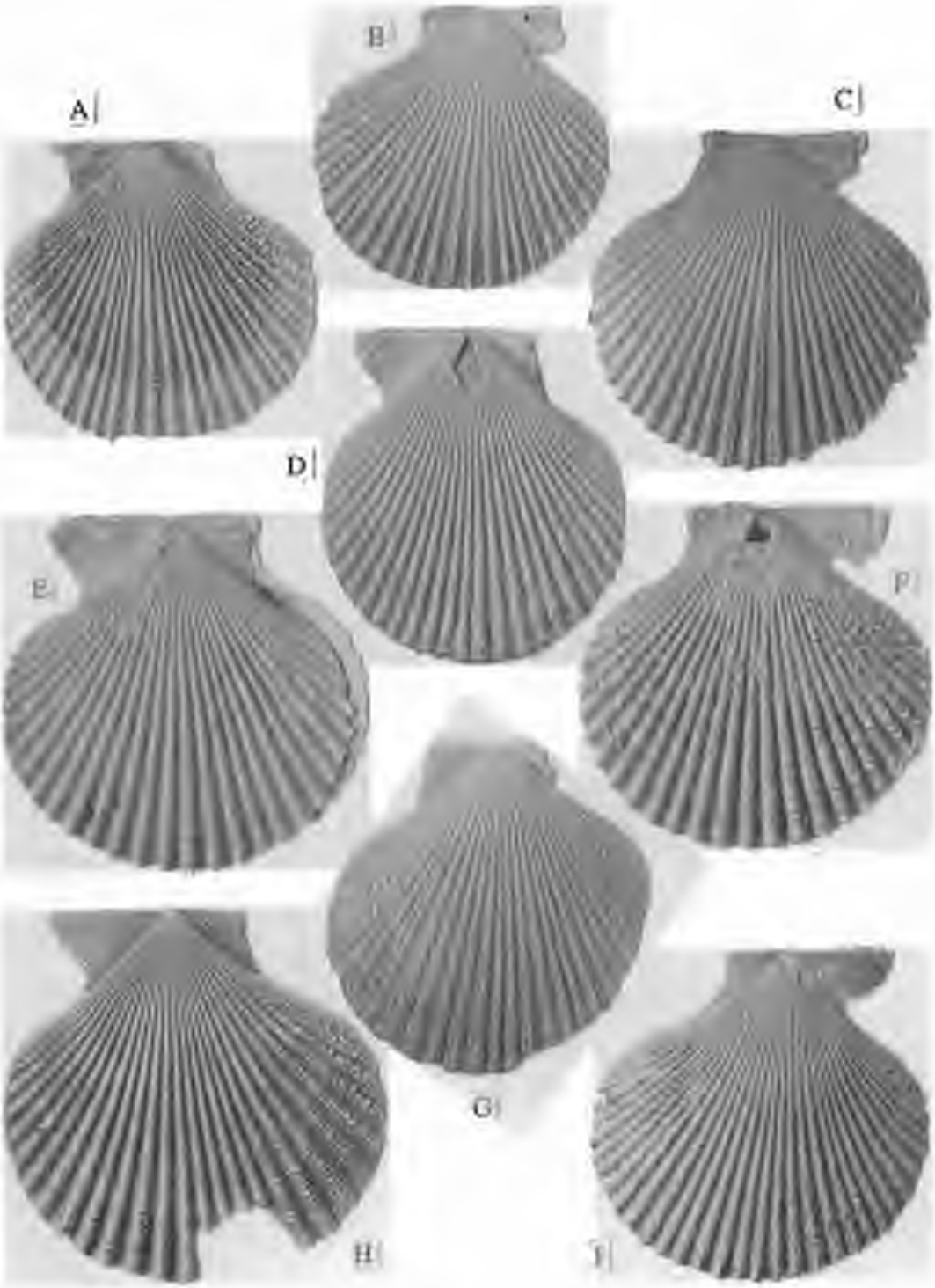
Type material. Holotype, NMV P301355, paired valves, PL3011, Browns Creek Clay (Aldingan), 10 m below greensand bed, washout nearest Browns Creek, Johanna coast of southern Victoria, map ref. Glen Aire 079058, coll. T. A. Darragh, 28.x.1971; paratype, NMV P302792, LV, all data as holotype; paratype, NMV P301513, RV, PL3011, locality as above, coll. T. A. Darragh, 29.xi.1972; paratypes NMV P304574–5, LVs, locality as above, coll. T. A. Darragh, 24.ii.1971.

Other material examined. **Aldingan:** BROWNS CREEK CLAY: PL3011, Browns Creek (36 specimens); PORT WILLUNGA FORMATION: SAM T930F (1 specimen; one of Tate's unfigured paralectotypes of *Pecten peroni*, 'polyzoal limestone, Aldinga Bay'); PL3010, Blanche Point (2 specimens); PL3612, bore 240, Klemzig, SA (10 specimens); NANARUP LIMESTONE: WAM, PL506, Nanarup lime quarry (15 specimens); PALLINUP SILTSTONE: WAM 63.76, Woogenellup, via Mt Barker, WA (1 specimen); WAM 70.1813, crossing of Bremer River, 14 km NW of Bremer Bay township, WA, map ref. Bremer Bay 223 761 (1 specimen); WAM 71.216, near Hunter River mouth, 200 m from beach, Bremer Bay district, map ref. Cheyne Beach 240 754 (1 specimen); WAM 76.1230, beside dam 3.2 km E of Lort River, 0.8 km N of Albany–Esperance Rd, WA (1 specimen); WAM 85.36, gully by main road, Bremer Bay townsite, WA (1 specimen, part and counterpart); WAM 86.472, Mettler Lake Nature Reserve, WA (1 specimen).

Occurrence and time range. Apparently restricted to Aldingan (Late Eocene); recorded widely across southern Australia: Browns Creek, Johanna, Victoria; Adelaide bores and Aldinga Bay, South Australia; Nanarup Limestone and Pallinup Siltstone in southern Western Australia.

Remarks. This new species is closely similar to *T. keiloriana* in most characters and makes a very plausible direct ancestor for that species. *T. badioriva* sp. nov. differs from *T. keiloriana* in its smaller maximum size, its much more prominent LV preradial dissoconch sculpture, with obvious commarginal ridges and antimarginal ridgelets surrounding the pits (rather than merely extremely shallow, elongate pits as in *T. keiloriana*), and in a much higher proportion of specimens (up to *c.* 80% of the well preserved Browns Creek Clay specimens) having the finely subdivided costae and intricately frilled costal scales, which give this species group a distinctive appearance but which are seen on only perhaps 30% of specimens of *T. keiloriana*, and are still more elaborated in *T. multilamellata*. The shallowly V-shaped commarginal lamellae on the disc after costal inception but before costal subdivision are seen weakly on only a few specimens of *T. keiloriana*, but are present on most well preserved specimens of *T. badioriva*. These V-shaped commarginal lamellae were initially considered by us to be possible homologues of those illustrated on *Aequipecten opercularis* (Linné) by Waller (1991: pl. 4, fig. 9) and stated by Waller (1991: 32) to be characteristic of the Tribe Aequipectinini. However, SEM examination of *A. opercularis* showed that the ventral flexure of the commarginal lamellae in *Aequipecten* is quite different in shape and formation from that of *Talochlamys*, and *Aequipecten* differs further in having extremely coarse, deep, simple, circular pits on the LV preradial dissoconch, and prominent internal rib carinae. The resemblance in commarginal lamellae is therefore another convergent character.

Fig. 31. A, D, F, H, *Talochlamys badioriva* sp. nov., LV, silicone cast from incomplete natural mould, WAM 86.472, Pallinup Siltstone (Aldingan), Mettler Lake Nature Reserve, Western Australia; enlargements of partial mould, × 3.7 (A, H 12.8 mm) and of sculpture; D, F, sculpture of preradial dissoconch (D × 25) and area of costal inception (F × 55); H, sculpture near centre of disc, × 30. B, C, E, G, I, *Talochlamys eyrei* (Tate), SEM enlargements of juvenile LVs: B, WAM 88.762, Port Willunga Formation (Janjukian), 100–200 m S of Onkaparinga Trig station, near Adelaide, South Australia, very small juvenile, × 7; C, E, G, I, P300425, Tortachilla Limestone (early Aldingan), 'lower beds, Aldinga', ie., coast SW of Adelaide, South Australia: C, whole shell, × 4 (H 11.1 mm); and enlargements of poorly preserved sculpture of preradial dissoconch (E × 28), at costal inception (G × 40), and near ventral margin (I × 32).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Natural moulds of the exterior of small, finely sculptured pectinids in Pallinup Siltstone from southern Western Australia were studied by SEM as silicone rubber impressions, and showed enough sculptural detail (Fig. 31A, D, F, H) in common with the well preserved shells from Browns Creek for a positive identification as *T. badioriva*.

Etymology. The specific name (Latin, '*badius*', brown + '*rivus*', stream) refers to the type locality of the species, Browns Creek.

Talochlamys eyrei (Tate, 1886)

Figs 31B, C, E, G, I, 32G, 33A–E, 34A–G

Pecten eyrei Tate, 1886: 107, pl. 8, figs 3a, b, 6.
Pecten flindersi Tate, 1886: 108, pl. 8, fig. 7.
Pecten peroni Tate, 1886: 108, pl. 10, fig. 1a, b.
Chlamys eyrei; Ludbrook, 1969: fig. 96.1.

Description. Large for genus (height to 60 mm and rarely to 80 mm), weakly inflated, the two valves about equally inflated; umbonal angle low to moderate (as low as 80° in small juveniles, 105–110° in large adults); acline to weakly prosocline. Exterior sculptured with *c.* 27–52 radial costae, varying greatly in width, prominence and degree of subdivision within one sample, from only *c.* 27–35 wide, prominent, weakly subdivided costae to *c.* 40–52 narrow, closely spaced, complexly subdivided and intercalated costae; specimens with few, wide costae have many closely spaced, very wide, moderately high, ventrally directed scales on costal crests that extend laterally beyond crests and, in extreme specimens, almost meet across radial interspaces, whereas narrowly costate specimens have many markedly narrower, spine-like, ventrally directed scales on costal crests. Radial interspaces sculptured with fine, close antimarginal ridgelets and, in a few well preserved specimens, shagreen microsculpture. Form consistently chlamydoid throughout life, RV anterior auricle with deep, narrow byssal notch and functional ctenolium; LV anterior auricle moderately long, tall, with anterior margin weakly sinuous to convex, sloping towards anterior; posterior auricles small, with weakly to quite strongly concave posterior outline, sloping strongly towards anterior; all auricles sculptured as on neighbouring disc, dorsal margins of RV auricles weakly serrate. Interior weakly corrugate, without rib carinae; hinge with low, thin dorsal and resilial teeth, not well preserved on material seen.

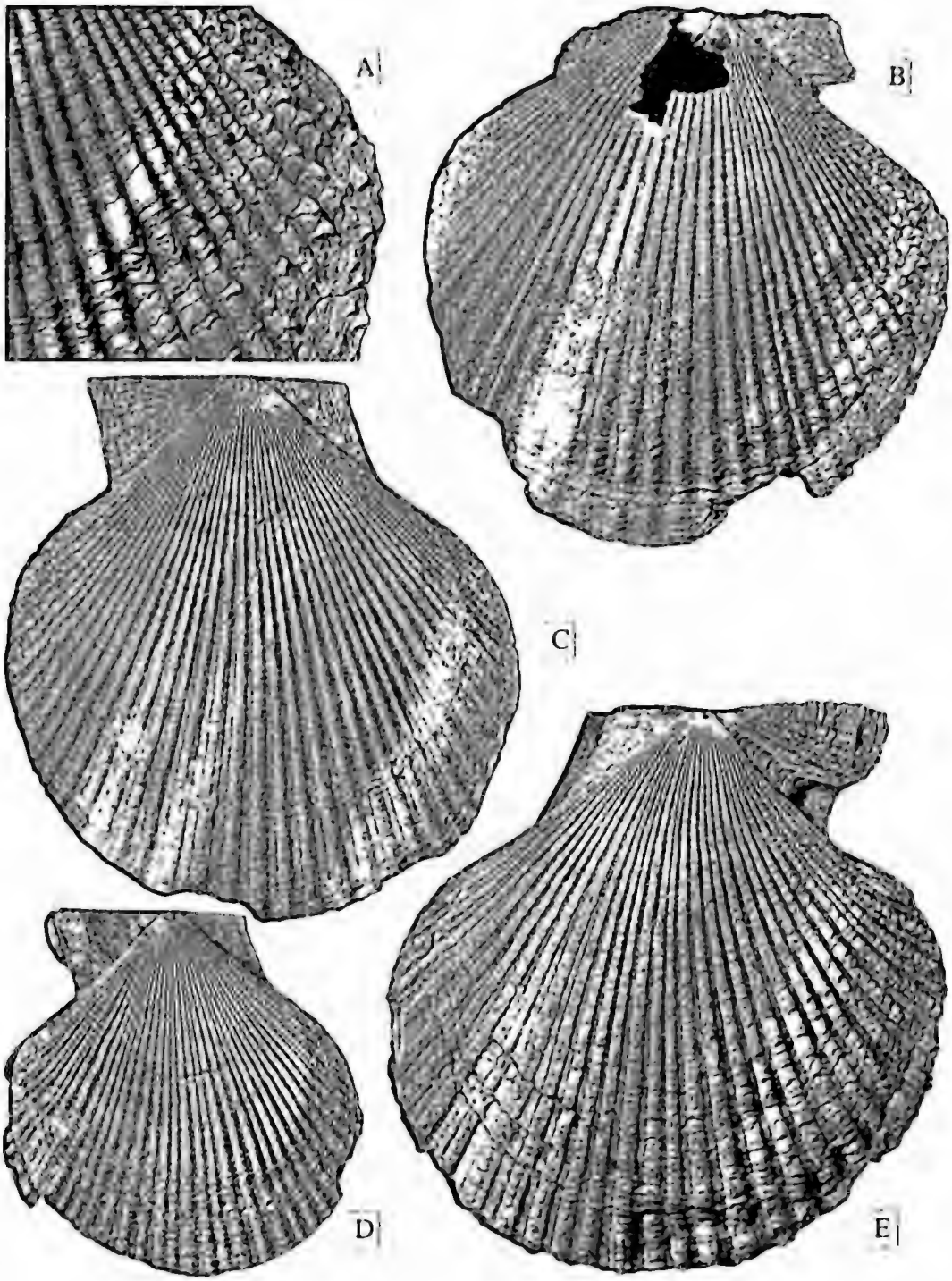
Dimensions.

Lectotype of *P. eyrei* Tate SAM T941A	H 48.6	L 46.1	RV
Lectotype of *P. flindersi* Tate SAM T931B	56.3	55.0	RV
Lectotype of *P. peroni* Tate SAM T930A	40.7	38.3	LV
Large 'Adelaide' specimen SAM T931A	80.0	77.5	RV

Type material. Lectotype of *Pecten eyrei* Tate, 1886, designated here, SAM T941A, Tate's (1886: pl. 8, fig. 3b) figured syntype, from 'polyzoal rock, Aldinga Bay', with 3 paralectotypes, SAM T941B–D; lectotype of *Pecten flindersi* Tate, 1886, designated here, SAM T931B, Tate's (1886: pl. 8, fig. 7) figured syntype, from 'glauconitic limestone, Aldinga Bay'; with 5 paralectotypes, SAM T931C–G, and one specimen apparently added to types after publication, SAM T931A; lectotype of *Pecten peroni* Tate, 1886, designated here, SAM T930A, Tate's (1886: pl. 10, fig. 1a) figured syntype, from 'polyzoal limestone, Aldinga Bay', with 9 paralectotypes, SAM T930B–J; *Pecten flindersi* Tate, 1886, 6 unfigured paralectotypes, SAM T943A–F, from 'Adelaide bore'; these last are an otherwise unknown taxon, described below under *Mimachlamys*.

Other material examined. **Aldingan:** BLANCHE POINT MARL: Maslin Bay (4 specimens); BROWNS CREEK CLAY: lowest bed in Castle Cove, Glenaire (1 specimen); TORTACHILLA LIMESTONE: lower beds, Aldinga (47 specimens); Maslin Beach, towards Blanche Point, Port Willunga (2 specimens); PL3464, Tortachilla Trig (19 specimens); WAM, Tortachilla Lst, Maslin Beach (7 specimens); AMS F1724, Aldinga, pres. Prof. R. Tate, 1892

Fig. 32. A–C, *Talochlamys badioriva* sp. nov., from PL3011, Browns Creek Clay (Aldingan), 10 m below greensand bed, Browns Creek, coast W of Cape Otway, Victoria, enlarged, × 1.5: A, B, holotype, P301355, LV (A) and RV (B); C, paratype RV, P301513. D–F, *Talochlamys laticostata* sp. nov., Morgan Limestone (Balcombian), Murray River, South Australia: D, narrow paratype, LV of articulated pair, P302144, 'upper part of lower beds, Murray River cliffs at Morgan', enlarged, × 1.25; E, F, holotype, LV and RV of articulated pair, P301523, 'lower beds, River Murray cliffs at Morgan', enlarged, × 1.5. G, *Talochlamys eyrei* (Tate), incomplete RV, P302080, from PL3187, Mannum Formation (Longfordian), quarry on East Front Road, 300 m W of canoe tree, Younghusband, E bank of Murray River, South Australia. H, I, *Talochlamys keiloriana* (Crespin), Muddy Creek Formation (Balcombian), Grange Burn, tributary of Muddy Creek, near Hamilton, western Victoria; both enlarged, × 1.25: H, LV, P302141, *c.* 1 km upstream from Henty's house, Grange Burn; I, RV, P302142, bed of Grange Burn approx. 800 m upstream from Forsyth's Bank.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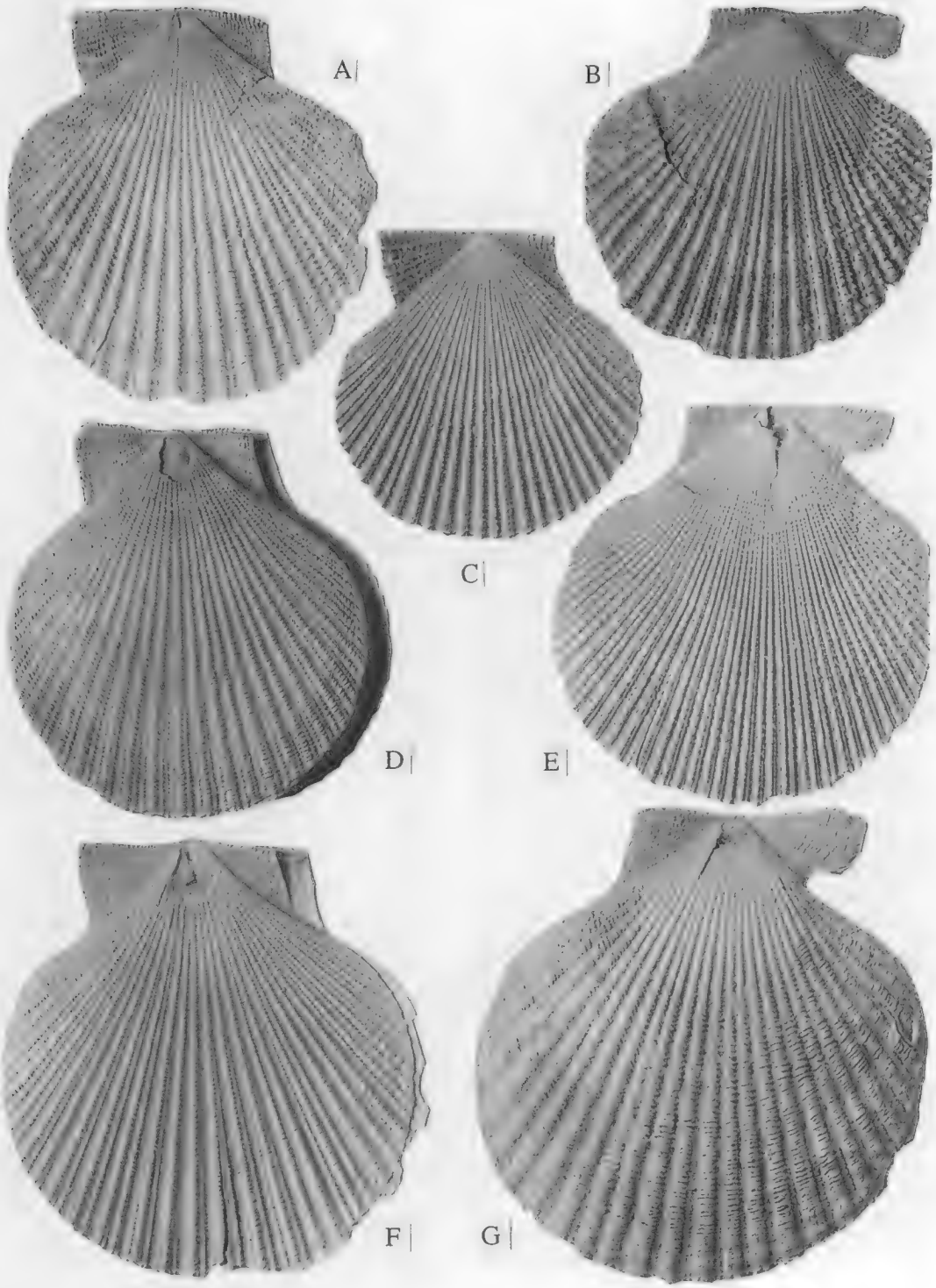
(2 specimens); AMS C129228, Aldinga (4 specimens); PL3297, mouth of Onkaparinga River (103 specimens); WILSON BLUFF LIMESTONE: No. 5 bore, 32 km N of Nullarbor Station, SA (1 specimen); WAM 71.1390, above Notostrea bed, cliff 1.8 km E of cairn, Wilson Bluff, WA (1 specimen); ROGUE FORMATION: PL3283, Port Julia (8 specimens); PL3284, 1 km S of Port Julia (7 specimens). **Willungan:** PORT WILLUNGA FORMATION: PL3618, Onkaparinga Trig (130 specimens); PL6669, S of Onkaparinga Trig (46 specimens); WAM 88.763–4, 100–200 m S of Onkaparinga Trig, bed 2, yellow-green (3 specimens); WAM 88.809, 200 m S of Onkaparinga Trig (4 specimens); WAM 88.827–9, 200–300 m S of Onkaparinga Trig, bed 3, grey bryozoal bed (4 specimens); WAM 88.841, 300 m S of Onkaparinga Trig, coarse bryozoal unit (1 specimen); PL3285, Dowcer Bluff (8 specimens). **Janjukian:** GAMBIER LIMESTONE: PL3283, Commercial Minerals quarry, Marte (7 specimens); railway quarry 12 km NNW of Mt Gambier (1 specimen); CALDER RIVER LIMESTONE: GSV Aw3, Aire Coast, Glenaire (2 specimens); GSV Aw4, W of Aire River, Glenaire (1 specimen); CLIFTON FORMATION: Alkemade Lime Quarry, Ka Wa Limeworks, Kawarren (1 specimen); Kawarren quarry (2 specimens); JAN JUC FORMATION: PL3025, Fishermans steps, Torquay (6 specimens); bed just above Bird Rock cap, Torquay (2 specimens); Bird Rock cliffs, Torquay (27 specimens); Torquay (23 specimens); PORT WILLUNGA FORMATION: PL3286, Port Vincent (27 specimens); PL3287, S of Port Vincent (20 specimens); PL3288, Klein Point (156 specimens); PL3292, Wool Bay (2 specimens); PL3293, Stansbury (19 specimens); lower 3 m of cliffs S of jetty, Port Willunga, Yankalilla 685 945 (22 specimens); lower beds, Aldinga (13 specimens); Aldinga (12 specimens); WAURN PONDS LIMESTONE: Waurn Ponds (10 specimens); Harris Quarry, Waurn Ponds, Geelong 345 872 (2 specimens); WAM 86.304, Waurn Ponds, old quarry (1 specimen); POINT ADDIS LIMESTONE: PL3277, Point Addis (4 specimens); Aireys Inlet (3 specimens); WAM 85.437, 50 m E of steps, SW corner of Pt Addis (1 specimen); POINT TURTON LIMESTONE: PL3290, Point Turton (10 specimens). **Longfordian:** FISHING POINT MARL: PL3034, S side Lake Costin (1 specimen); MANNUM FORMATION: PL3184, quarry, East Front Rd, Taworri (15 specimens); PL3185, Panorama Ave (7 specimens); PL3187, quarry, East Front Rd, Younghusband (24 specimens); PL3191, cutting, Klose Rd, Mannum (95 specimens); lower beds, Murray River cliffs at Wongulla (16 specimens); lower beds, Murray River cliffs from Wongulla to Mannum (6 specimens); WAM 85.763, small pit 5.5 km S of Younghusband store, E bank Murray River, Mannum district (1 specimen); MELTON LIMESTONE: PL3295, Myponie Point (7 specimens); PL3296, N of Black Rock (4 specimens); PUEBLA FORMATION: mouth of Jan Juc Creek (1 specimen); SANDFORD LIMESTONE: PL3161, Runnymede Quarry (1 specimen); ZEALLY LIMESTONE: yellow polyzoal limestone between Torquay village and Jan Juc Creek (2 specimens).

Occurrence and time range. Aldingan–Longfordian; Aldingan and Willungan formations in the St Vincent Basin, Mannum Formation in the Murray Basin, and Janjukian and Longfordian formations in the Otway Basin at Torquay, Kawarren and Waurn Ponds.

A specimen illustrated by Ludbrook (in Lowry 1970: fig. 21G), under the name '*Chlamys peroni*', from Abrakurrie Limestone (Longfordian) at Murra-el-elevan Cave, Nullarbor Plain (Eucla Basin, southwestern Western Australia) has been examined (in GSWA) and appears likely to be correctly referred to *T. eyrei*.

Remarks. Comparison of Tate's type series of *Pecten eyrei*, *P. flindersi* and *P. peroni* with a large collection of specimens from the type and neighbouring localities on the Aldinga coast near Adelaide (most from Tortachilla Limestone, others from the overlying Port Willunga Formation) showed that only one species is represented by most of the material. Several factors led to the recognition of more than one species by Tate. Firstly, Tate's type specimens show a very wide range of variation in costal width and prominence, and in the presence or absence of narrow to extremely wide scales on the costal crests. Secondly, a systematic preservational difference seems to have affected specimens from different lithologies. Specimens from Port Willunga Formation in general show much better preservation of sculptural detail than specimens from Tortachilla Limestone; a few Port Willunga Formation specimens have beautifully preserved shagreen microsculpture over much of the intercostal surface, whereas we have observed a weak, abraded remnant of shagreen on only one specimen from Tortachilla Limestone. The specimens illustrated by Tate (1886: pl. 8, figs 3a, b, 6) with high, ventrally directed, extremely wide costal scales, their edges almost meeting across the radial interspaces, were

Fig. 33. Talochlamys eyrei (Tate), part of Tate's (1886) type material of *Pecten flindersi*. A, B, large unfigured paralectotype(?), RV, SAM T931A, possibly added to type tablet after 1886, 'Adelaide', ie., presumably Government House excavation (Aldingan); B, RV at natural size, and A, anterior area of disc enlarged, × 2, to show large scales. C, unfigured paralectotype, LV, SAM T931D, enlarged, × 1.5. D, unfigured paralectotype, LV, SAM T931C, enlarged, × 1.5. E, RV of figured syntype, here designated lectotype of *Pecten flindersi* Tate, SAM T931B, an articulated pair glued to type tablet by the LV; 'glauconitic limestone, Aldinga Bay', ie., Tortachilla Limestone, early Aldingan.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identified by Tate as *P. eyrei*, and most of his type material identified by this name seems to have come from Port Willunga Formation at either Aldinga ('polyzoal rock, Aldinga Bay') or the mouth of the Onkaparinga River, to judge from their white or grey shell material and brownish grey, soft sandy matrix. Tortachilla Limestone specimens, in contrast, have a hard, pale apple green, fine-grained matrix, the shell material is deep cream to pale yellow, and most specimens seem to have had the outer shell surface and costal spines removed by a chemical weathering process (dissolution rather than abrasion). Tate's types of *P. flindersi* seem mostly to have come from Tortachilla Limestone ('glauconitic limestone, Aldinga Bay; glauconitic sands, Adelaide bore') and their apparent sculptural difference from the types of *P. eyrei* is due more to preservational differences than to original sculptural differences. Tate's types of *P. peroni*, on the other hand, are a mixture of sculptural types from a mixture of lithologies; some are narrowly ribbed, finely scaly specimens of *P. eyrei/P. flindersi* from Port Willunga Formation, whereas the unfigured syntypes from the Adelaide (Kent Town) bore seem to be the basis of his description of the costae as having 'short triangular spines' as compared with 'crescentic scales', and to be the basis of his (Tate 1886: pl. 10, fig. 1b) illustration of the three separate scales on each primary costa and its neighbouring costellae, now seen as characteristic of *T. badioriva* sp. nov. The shell illustrated by Tate (1886: pl. 10, fig. 1a) as *P. peroni* is shown by the rather rounded RV anterior auricle and by comparison of the actual specimens with the figures to be a finely costate specimens of *P. eyrei/ P. flindersi*, and is designated here as the lectotype of *P. peroni*. Thus, in our opinion, even Tate's own type specimens of these three nominal 'species' intergrade completely, and comparison with large collections from localities south of Adelaide demonstrates that only a single species is present—apart from the confusion with some specimens we refer to *T. badioriva* sp. nov., all of which probably are from the Adelaide (Kent Town) Bore. As first revisers, we select the name *Pecten eyrei* to be the valid name for the species named *Pecten eyrei*, *Pecten flindersi* and *Pecten peroni* by Tate (1886).

Talochlamys eyrei is large for the genus, commonly reaching *c.* 60 mm high; Tate added a specimen to the type block of *P. flindersi* (after publication of the description) that is 80 mm high; it is labelled 'Adelaide', but has matrix of weathered, green Tortachilla Limestone. The large size, weak inflation, highly varied sculpture (both in costal number and width and in the size of the scales on the costae) and the very scaly costae of most specimens of this species make it easily recognisable. Apart from the larger size, *T. eyrei* differs from the species of the *T. badioriva–T. keiloriana* lineage in its longer (wider) disc and its differently shaped auricles. The posterior auricles have a much more concave posterior outline in *T. badioriva* and *T. keiloriana* than the tall, nearly straight, forward-inclined (towards the dorsum) posterior outline of *T. eyrei* and, in particular, the LV anterior auricle is lower, longer and much more sinuous than the tall, nearly straight, less obviously forward-inclined LV anterior auricle of *T. eyrei*. Some specimens from localities markedly younger than those of Tate's types (notably Mannum Formation on the Murray River) are indistinguishable from *T. eyrei*, which therefore has a significantly longer time range than previous records would suggest.

Specimens from Tortachilla Limestone at Aldinga (Fig. 33C, D) have an overgrowth of fine crystals obscuring the shell surface, and are unsuitable for SEM study, although the complete juvenile specimen studied at least demonstrates the presence of antimarginal ridgelets very early in ontogeny, and also the presence of shagreen-like, partly overgrown sculpture further down the shell. The most complete juvenile specimen from Port Willunga Formation (Fig. 31C, E, G, I) demonstrates that prominent commarginal sculpture is present on the LV preradial dissoconch, and again has antimarginal ridgelets in the hollow between the disc and the posterior auricle. The LV preradial sculpture seems to have been similar to that of *T. dichroa*, and a

Fig. 34. Talochlamys eyrei (Tate), part of Tate's (1886) type material of *Pecten eyrei* and *Pecten peroni*, all enlarged, × 1.5, except C (enlarged × 2.5). A, G, from 'polyzoal rock, Aldinga Bay', ie., Port Willunga Formation (late Aldingan–Willungan): A, paralectotype of *Pecten eyrei*, LV, T941C of which auricles figured (Tate 1886: pl. 8, fig. 3a); G, figured syntype RV, T941A, here designated lectotype of *Pecten eyrei* Tate. B, D–F, four of the 10 syntypes of *Pecten peroni* from 'polyzoal limestone, Aldinga Bay', ie., Port Willunga Formation (late Aldingan–Willungan): B, paralectotype, SAM T930F, RV; D, paralectotype, SAM T930A, LV of articulated pair; E, SAM T930C, RV, figured syntype (here designated lectotype) of *Pecten peroni* Tate; F, paralectotype, SAM T930E, LV of articulated pair. C, unfigured paralectotype of *Pecten peroni*, LV, one of 12 on tablet, SAM T934A, from 'Adelaide Bore', ie., Kent Town bore, Aldingan; enlarged, × 2.5.

position in *Talochlamys* appears to be reasonable, despite the large size attained by adults. Also, the juvenile in Fig. 31I has wavy, ventrally cupped costal scales similar to those of *T. badioriva*, again supporting a position in *Talochlamys*.

Talochlamys multilamellata sp. nov.

Fig. 35A–C, E

Description. Moderate-sized for genus (to *c.* 33 mm high), acline to very weakly prosocline, the two valves similarly and only moderately weakly inflated, equidimensional to slightly longer than high; umbonal angle *c.* 110°. LV preradial sculpture not seen. Disc sculpture of *c.* 38–42 moderately elevated, moderately wide radial costae, with each radial interspace slightly to markedly narrower than one costa, costae subdividing to form pairs of similar costae over part of disc of many specimens, intercalating major secondary costae in a few interspaces of some specimens, and intercalating minor, low, narrow secondary costellae over distal half of disc on many specimens, regularly arranged in centre of each interspace on a few specimens; crossed by many low, rather closely spaced commarginal lamellae, raised into low, simple scales normal to costae on costal crests and across interspaces of closely spaced, subdivided costae, but only weakly continuous as low growth ridges across primary radial interspaces; scales extend laterally beyond costal margins in interspaces of well preserved specimens and form low, triangular projections extending beyond costal margins on some specimens. Floor of intercostal spaces bearing low, narrow, closely spaced antimarginal ridgelets over entire shell, ridgelets straighter than in *T. keiloriana*, not obviously broken up into radiating 'bundles' at commarginal ridges. Auricles low, moderately wide; RV anterior auricle with

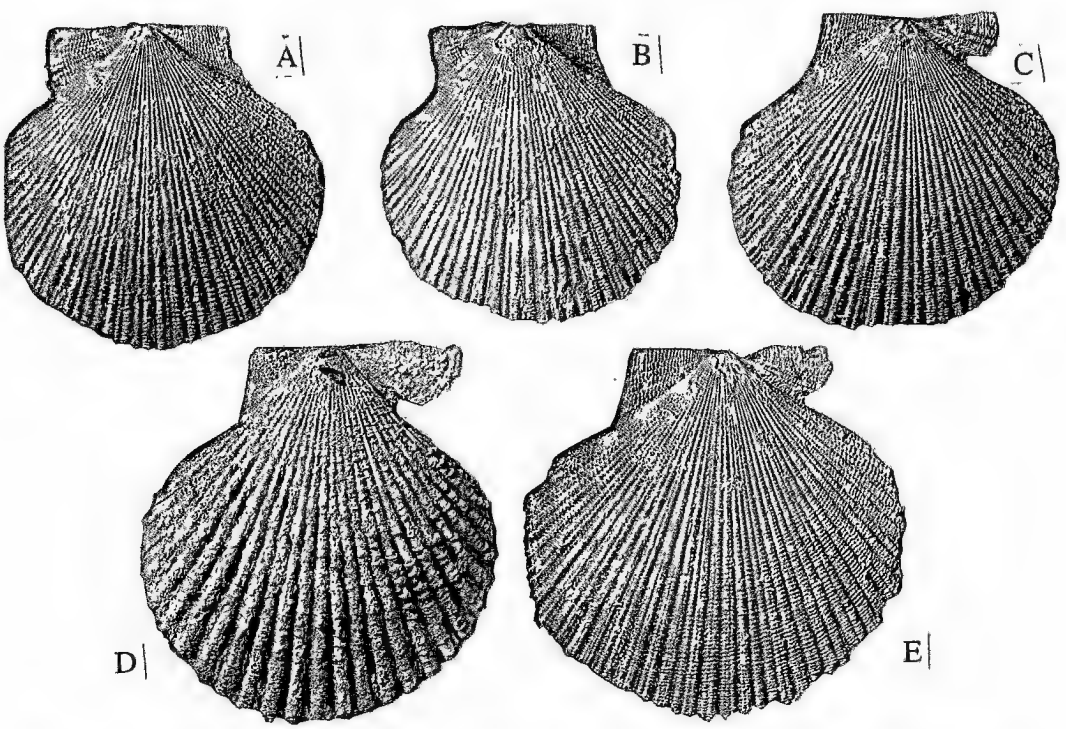


Fig. 35. A–C, E, *Talochlamys multilamellata* sp. nov., Abrakurrie Limestone (Longfordian), spoil from well at Moodini, *c.* 23 km E of Madura roadhouse, at foot of Hampton Escarpment, Eucla Basin; all enlarged, × 1.5: A, paratype, LV, WAM 69.815b; B, paratype, LV, WAM 69.815c; C, paratype, RV, WAM 69.815d; E, holotype, RV, WAM 69.815a. D, *Talochlamys laticostata* sp. nov., paratype, RV, P302143, specimen with coarse, dorsally concave scales; Morgan Limestone (Balcombian), 'upper part of lower beds, Murray River cliffs, Morgan', South Australia; enlarged, × 1.5.

moderately deep, narrow byssal notch, deeply depressed byssal fasciole and functional ctenolium in adult; ctenolium with 4–5 stout, hooked teeth; outer face of auricle, above byssal fasciole, sculptured with 5–6 low, wide, coarsely scaly radial costae. LV anterior auricle moderately tall, anterior margin slightly sinuous, inclined weakly towards anterior; sculptured with *c.* 10 low, wide, closely spaced, scaly radial costae; posterior auricles moderately tall, with only weakly concave posterior margins inclined weakly towards anterior; dorsal margins of RV auricles finely serrate. Interior smooth except for weakly notched ventral margin. Hinge (seen only in one incomplete RV) with very thin dorsal teeth and short, very thin, low, widely diverging resilial teeth.

Dimensions.

Holotype, WAM 69.815a	H 32.4	L 33.4	RV
Paratype, WAM 69.815b	27.0	28.1	RV
Paratype, WAM 69.815c	28.6	28.5	LV
Paratype, WAM 69.815d	26.6	26.5	LV

Type material. WAM 69.815, Abrakurrie Limestone (Longfordian), spoil from well at ruin, Moodini Bluff, Eucla Basin, *c.* 23 km east of Madura roadhouse, at foot of Hampton Escarpment, southeastern Western Australia, grid ref. Madura 530054, coll. T. A. Darragh, M. Archer & G. W. Kendrick, 5.iii.1969; holotype, WAM 69.815a, a large RV, and 9 paratypes.

Other material examined. NMV P300550, all data as above (1 specimen).

Occurrence and time range. Known only from a single block of Abrakurrie Limestone (Longfordian) collected from well spoil. Likely to occur widely in Abrakurrie Limestone in the Eucla Basin.

Remarks. Talochlamys multilamellata sp. nov. bears a close general resemblance to *T. keiloriana*, but they are distinct in many characters. The radial costae of *T. multilamellata* are much more irregularly subdivided and intercalated than those of any of the other species referred here to *Talochlamys*, except for the Recent *T. pulleineana*. The shape of *T. multilamellata* is considerably lower, wider and more weakly inflated than in most other species referred here to *Talochlamys*, although *T. badioriva* sp. nov. is, if anything, more weakly inflated than *T multilamellata*. The costal scales also are wider, lower and simpler than in all the other species referred to *Talochlamys* here; although resembling those of the other species closely in appearance, they are simple, thin flanges rather than hooked or cupped scales (but all the material has been removed from hard limestone, so part of the scales might have been broken off all the material). Finally, the 'bundles' of short lengths of antimarginal ridgelets, broken up by ventrally convex growth lines, that characterise the other Australian fossil species of *Talochlamys* are not seen in *T. multilamellata*, in which the antimarginal ridgelets are simple and straight near the centre of the disc. Nevertheless, the close overall resemblance to *T. keiloriana* is taken as evidence of relationship at present, for want of other criteria. *T. multilamellata* has a curious mixture of chlamydinine characters (irregularly subdivided and intercalated costae, simple antimarginal ridgelets in all radial interspaces, lack of internal rib carinae) and more advanced characters (the rather low, wide shape, and the wide umbonal angle with low, wide ears) and its true taxonomic position will not be clear until the LV preradial sculpture can be revealed.

Talochlamys multilamellata occurred in the same block as *Abrachlamys toolinnensis* gen. nov., sp. nov., named above, although the latter was much the less common of the two; *A. toolinnensis* occurs more widely than *T. multilamellata* in the Abrakurrie Limestone samples available to us, and is easily distinguished by having very little costal subdivision, and by having costal scales on the disc of the LV only, rather than on both valves as in *A. toolinnensis*.

Etymology. The specific name (Latin, '*multus*', many +'*lamella*', a lamella or thin plate) refers to the unusually numerous, prominent scales of the type species.

Talochlamys laticostata sp. nov.

Figs 32D–F, 35D

Description. Moderate-seized for genus (to 40 mm high), acline to very weakly prosocline, moderately well inflated, inflation of the two valves approximately equal; a few specimens slightly taller than long, most slightly longer than tall, with relatively wide umbonal angle (most specimens *c.* 100°, a few as low as 95°). LV preradial microsculpture not seen. Disc sculpture of 25–32 wide, well raised, convex-topped radial costae, simple, undivided and fixed in number on most specimens, identical on the two valves, developing weak, smooth lateral secondary costellae alongside primary ones on a few specimens; costal crests bearing wide, widely spaced scales that are low and inconspicuous over much of surface of most specimens (incomplete) but when not abraded are very large for genus,

initially curved slightly ventrally but then strongly and deeply cupped towards dorsum, almost hemispherical on some specimens, little wider than costae, not continuing down costal sides and on to edges of intercostal spaces as in *T. keiloriana*. Entire surface bearing low, narrow antimarginal ridgelets, well preserved on costal crests on most specimens, forming short, weakly radiating groups of ridgelets that stop at ventrally convex growth lines in intercostal spaces; no commarginal sculpture observed. RV anterior auricle long and narrow, retaining deep byssal notch, depressed byssal fasciole and functional ctenolium in adult, main outer face above byssal fasciole sculptured with 6–7 coarsely scaly radial costae; LV anterior auricle long, with weakly sinuous anterior margin inclined strongly towards anterior, sculptured with *c.* 7–9 scaly radial costae; posterior auricles moderately short, with weakly concave posterior outline, sculptured with 8–10 very narrow, widely spaced, finely scaly radial costae. Dorsal margin of RV auricles coarsely serrate. Interior smooth apart from weakly notched ventral margin. Hinge with long, narrow dorsal teeth and short, very narrow resilial teeth occupying dorsal half of edges of resilifer.

Dimensions.

Holotype, P301523	H 35.8	L 36.3	2 valves
Paratype, WAM 92.283			
Cadell Marl	33.2	32.3	LV
Paratype, P302143, Morgan	33.4	31.4	RV
Paratype, P302144, Morgan	39.1	35.6	2 valves

Type material. Holotype, NMV P301523, an articulated pair, from Morgan Limestone (Balcombian), 'lower beds, River Murray cliffs at Morgan', South Australia, coll. F. A. Cudmore; 2 paratypes, NMV P302143–4, one RV (P302143) and an articulated pair, Morgan Limestone, 'upper part of lower beds, Murray River cliffs, Morgan', South Australia, coll. F. A. Cudmore; paratype, WAM 79.16, Cadell Marl member, Morgan Limestone (Balcombian), left bank Murray River 6.4 km downstream from Morgan, South Australia, coll. G. W. Kendrick, 3–4.iii.1978; paratype, WAM 92.283, locality as WAM 79.16, coll. W. G. Buick.

Other material examined. **Balcombian:** MORGAN LIMESTONE: PL3217, Murray cliffs, 'Yarra View' (2 specimens); River Murray cliffs 6.4 km below Morgan (8 specimens); lower beds, River Murray cliffs at Morgan (6 specimens); AMS F5893, cliff 44, Parish of Waikerie, Murray River (3 specimens). **Bairnsdalian:** PATA LIMESTONE: PL3213, Ramco Point (2 specimens).

Occurrence and time range. Balcombian and Bairnsdalian; known only from Morgan and Pata Limestones in the Murray Basin.

Remarks. Talochlamys laticostata sp. nov. is similar to *T. keiloriana* in general appearance, but the many differences and the lack of knowledge of the LV preradial sculpture make a relationship to *T. keiloriana* uncertain. *T. laticostata* is markedly more inflated than *T. keiloriana*, and although the number of radial costae is closely similar, the costae of *T. laticostata* are significantly wider and their interspaces are a little wider in *T. laticostata* than in *T. keiloriana*, presumably because each costa of *T. laticostata* occupies the same space as one costa and its two subsidiary costellae in *T. keiloriana*. The character taken to indicate their close phylogenetic relationship is the arrangement of the antimarginal ridgelets in intercostal spaces as short groups of weakly radiating ridgelets, each group ending at a ventrally convex growth line, producing a series of evenly spaced, radiating 'bundles' of ridgelets over most of the intercostal surface, closely similar in the two species. At first sight the unusually large and prominent, dorsally cupped costal scales, forming hemispherical knobs on the costae of well preserved specimens, seem to provide a major difference from *T. keiloriana*, but some unusually unabraded specimens of *T. keiloriana* have the outer tips of a few of their scales curved ventrally and then back up towards the dorsum, producing a scale similar to that of *T. laticostata*, but much narrower. Unfortunately, we have seen relatively few specimens of *T. laticostata*, and it seems likely that, if any small specimens have been collected, they are masquerading in collections of *Mimachlamys sturtiana*. Examination of LV juveniles by SEM is needed to confirm the position in *Talochlamys* adopted here, but the similarity to *T. keiloriana* in many characters leaves little real doubt of the generic position.

Etymology. The specific name (Latin, '*latus*', broad + '*costatus*', ribbed) refers to the relatively wide radial costae of this species.

Talochlamys keiloriana (Crespin, 1926)

Figs 32H, I, 36A–H, 37A–H

Chlamys keiloriana Crespin, 1926: 118, pl. 8, fig. 3.

Description. Moderate-sized (40–45 mm high), weakly to very weakly inflated, RV slightly more inflated than LV; umbonal angle moderate (100–105°); equidimensional or, in large specimens, length exceeding height, although specimens from youngest locality (Tambo River Formation, Lake Tyers, Gippsland) are narrower (umbonal angle

c. 90°) and have narrower costae than others assigned here; retaining chlamydoid to aequipectinoid form in adults. Exterior sculptured with *c.* 26–35 prominent, relatively wide, moderately widely spaced, convex-topped radial costae, fixed in number throughout ontogeny in many specimens, weakly dividing and intercalating near ends of disc on some specimens, subdividing to form one low, narrow secondary costella on each side of each primary costa (producing a fasciculate costal profile) regularly over entire disc on some specimens, costae remaining simple on many; crossed by low, thin, prominent, wide commarginal scales on most specimens, on many specimens scales wider than each costa, descending costal edges to fade out or, on some specimens, weakly join across radial interspaces as low, flexuous commarginal ridges; on most scaly specimens, scales weakly to deeply cupped with hollow facing ventrally, then turning out and up at narrower tip, which is directed dorsally; in specimens with costae in fasciculate groups, scales weakly to quite strongly subdivided into groups of three narrower scales; intercostal spaces floored with closely spaced antimarginal ridgelets, arranged in many specimens in short groups ('bundles') of diverging ridges, each group ending at an arcuate growth line or low commarginal ridgelet. RV anterior auricle long, high, with strongly pointed anterior extremity and deep, narrow byssal notch; LV anterior auricle long, high, with strongly sinuous anterior margin inclined strongly towards anterior, producing a strongly pointed anterior end; posterior auricles small, tall, with strongly concave ventral margins sloping strongly towards anterior; all auricles sculptured as on disc. Interior weakly corrugated, without rib carinae. Hinge weak, with low, narrow dorsal and resilial teeth in RV and correspondingly shallow sockets in LV.

Dimensions.

NMV P302141, Grange Burn	H 45.6	L 45.6	LV
NMV P302142, Grange Burn	39.6	40.0	RV
NMV P302139, Rose Hill	43.5	45.0	RV
NMV P302140, Rose Hill	40.2	39.7	LV

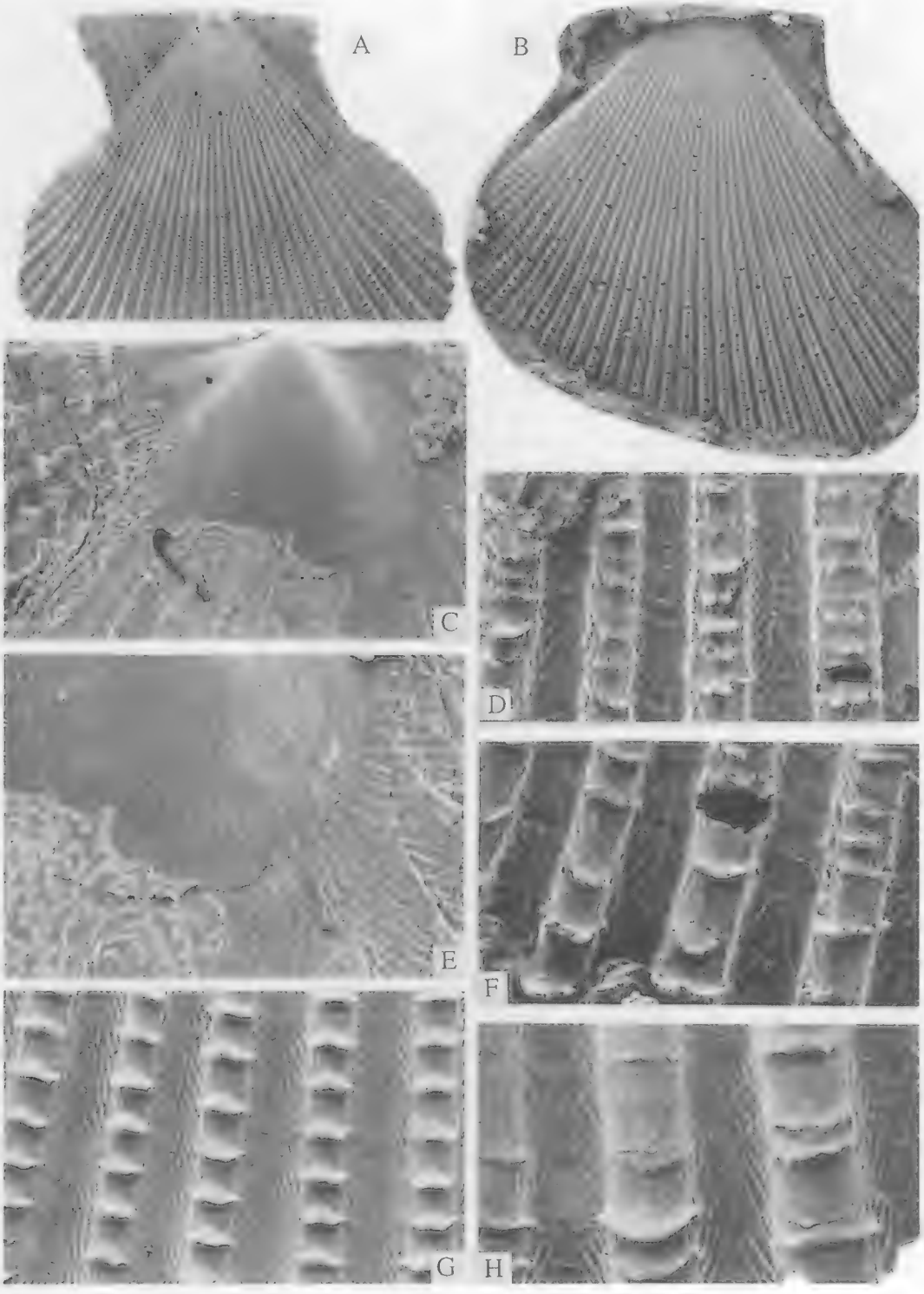
Type material. Chlamys keiloriana Crespin, 1926, holotype, NMV P13466, from Fyansford Formation (Balcombian), Green Gully, Keilor, near Melbourne; a small, incomplete, mid-disc section of a LV, preserved as a natural mould of the exterior, in ironstone.

Other material examined. **Balcombian:** FYANSFORD FORMATION: PL3072, GSV Ad28, Orphanage Hill, Fyansford (1 specimen); Green Gully, Keilor (1 specimen); MUDDY CREEK FORMATION: PL3082, Clifton Bank, Muddy Creek (12 specimens); Pat's Gully, on Henty's, Grange Burn, Yulecart (3 specimens; Balcombian/Bairnsdalian?); lower bed, Grange Burn, in gorge 1 km E of Henty's, Hamilton (16 specimens); GIPPSLAND LIMESTONE (Balcombian?): Newmerella (2 specimens); railway cutting 1.6 km W of Orbost (2 specimens). **Bairnsdalian:** BAIRNSDALE LIMESTONE: PL3174, Nelson Bros. Quarry (9 specimens); Bairnsdale (1 specimen); FYANSFORD FORMATION: PL3095, Ad15, Western Beach, Corio Bay (1 specimen); PL3100, Murgheboluc 4A (94 specimens); Grices Creek (5 specimens); Corio Bay, Geelong (1 specimen); GRANGE BURN FORMATION [REMANIÉ]: Forsyth's Bank, Grange Burn, Muddy Creek (2 specimens); just below main shellbed opposite Forsyth's Bank, Grange Burn (1 specimen); WUK WUK MARL: Windmill shaft on Mitchell River terrace, Rosehill farm, Bairnsdale (5 specimens). **Mitchellian:** TAMBO RIVER FORMATION: PL3267, Reedy Arm Peninsula, Lake Tyers (31 specimens).

Occurrence and time range. Balcombian to Mitchellian. The type locality, Green Gully, Keilor, is probably Balcombian in age. Few other specimens of this age have been seen, although the excellent, large specimens from the 'giant cowry locality' at Grange Burn might be as old as Balcombian. It is replaced in Morgan and Pata Limestones in the Murray Basin by *T. laticostata* sp. nov. *T. keiloriana* is particularly common at PL3100 (Fyansford Formation, Bairnsdalian). A few specimens have been seen from Bairnsdale Limestone in the Gippsland Basin, and it is common in Tambo River Formation (Mitchellian) at PL3267.

Remarks. Crespin (1926) described *Chlamys keiloriana* on the basis of a single, poor, incomplete natural mould of the exterior in ironstone, ie., the weathering remnant from a more normal Cenozoic lithology, presumably Fyansford Formation. The first problem with this species, then, has been to identify this taxon with a species we have recognised based on well preserved shells. SEM examination of a silicone rubber impression of the holotype (Fig. 36B, D, F) demonstrated that it has the wide costae, weakly diverging intercostal microsculpture (modified antimarginal ridgelets) and narrow-tipped, ventrally cupped costal scales, with flared edges descending the costal edges, that characterise a moderately common, large, weakly inflated, prominently costate, Balcombian to Mitchellian chlamydinine, which we therefore identify as *Talochlamys keiloriana*.

Talochlamys keiloriana has a weakly pitted LV preradial dissoconch (Fig. 36C, E). The prominent, finely frilled commarginal lamellae present in *T. pulleineana*, *T. dichroa* and *T. gemmulata* are not present in *T. keiloriana* and, instead of regularly frilling the lamellae, the antimarginal ridgelets of many specimens form a regularly diverging group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H

of short ridges, each group ('bundle') ending at a commarginally, ventrally convex, curved growth line. A few specimens have the shallowly V-shaped commarginal lamellae early on the disc that occur commonly on *T. badioriva* (well preserved on two small specimens in NMV P301321, Fyansford Formation, here Bairnsdalian, PL3100). Costal scales are narrow-tipped and ventrally cupped or hooked, as in *T. pulleineana*, but have the tip bent dorsally on some well preserved specimens; in many specimens, they descend to the intercostal spaces as narrow ridges on the costal sides. The largest and best-preserved specimens assigned here (to 45 mm high), from the Balcombian or, possibly, Bairnsdalian 'giant cowry locality' at Grange Burn, are very weakly inflated, relatively wide shells with 26–32 well raised, round-topped radial costae, with each interspace about equal to or slightly wider than the width of one costa. Most specimens have simple, undivided costae, with costal increase achieved by intercalation in the centre of intercostal spaces, but a number of specimens have costal margins subdivided to produce a narrow secondary costa against each side of most or all primary costae. The costal scales on these specimens are then subdivided over the fasciculate group of costae in a highly characteristic, elaborately frilled manner seen only in this group of species. A few specimens have one or a few of the secondary costae diverging more markedly from the primary costal edge to form a separate costa in the interspace. *T. multilamellata* sp. nov., in Abrakurrie Limestone (Longfordian), Eucla Basin, has similar but still more complexly subdivided costae and elaborately frilled scales, and seems to be closely related to *T. keiloriana*. Another previously unnamed species, *T. badioriva* (above), seen initially as elaborately scaly specimens from Browns Creek, Johanna, Victoria, includes many specimens with the same frilled scales in fasciculate costal groups as in those specimens of *T. keiloriana* that have fasciculate groups, but differs in having longer scales on a much higher proportion of specimens and more complex, shallowly V-shaped commarginal lamellae that have been seen on only a few specimens of *T. keiloriana*. *T. badioriva* therefore provides a feasible direct ancestor for *T. keiloriana*.

The youngest specimens assigned to *T. keiloriana*, from Tambo River Formation (Mitchellian) at Nowa Nowa Arm, Lake Tyers (PL3267), have a taller and narrower shape, rather narrower radial costae and narrower costal scales than most Balcombian–Bairnsdalian specimens, but are not markedly outside the range of variation of the older specimens. Specimens are common there, but have not been seen from any other localities as young; they seem to require particular ecological conditions.

Talochlamys spp. nov.?

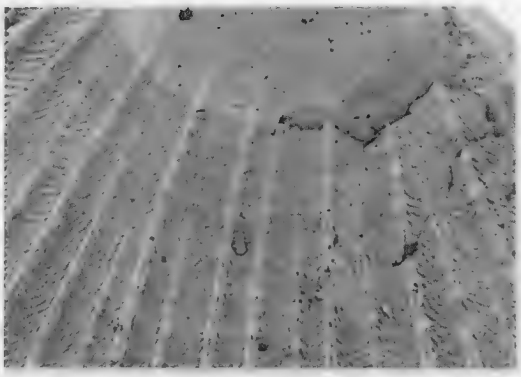
Remarks. The material before us includes several specimens of rather poorly preserved pectinids, resembling *Talochlamys* in general characters, but inadequate for description or for identification with any of the other species dealt with here. We give brief notes on the material to indicate the range of taxa as yet undescribed in the Australian fauna.

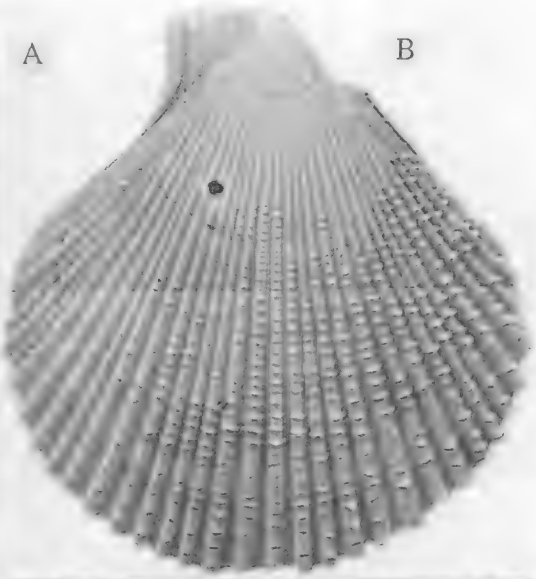
A. *Toolinna Limestone:* A single small LV from 'Toolinna Limestone' (ie., Toolinna Limestone facies of Wilson Bluff Limestone, of Late Eocene age) is very tall and narrow, with a narrow umbonal angle, and with *c.* 40 low, moderately wide, closely spaced, undivided radial costae. A few costae near the anterior and posterior ends of the disc bear quite coarse scales, and the auricles are very tall, and bear large, rounded scales on the costae. The radial interspaces bear antimarginal ridgelets. The affinities of this little shell are quite unknown, although superficially it resembles the slightly larger specimens referred to *Mimachlamys* sp. nov. among Tate's unfigured paralectotypes of *Pecten flindersi*, SAM T.943A–F, discussed below.

Material. WAM 89.152, 'Toolinna Limestone', spoil around Booanya Well, Namabinia Station via Balladonia, WA.

B. *Pallinup Siltstone* (Fig. 38B)*:* A silicone rubber cast from a natural mould in Pallinup Siltstone shows many characters unusually well for material from this formation (many other moulds in WAM are unidentifiable). The moderately large (H *c.* 35 mm) RV has a narrow umbonal angle, a long anterior auricle with a deep byssal notch, and

Fig. 36. Talochlamys keiloriana (Crespin), SEM enlargements. A, C, E, G, H, small LV, P300422, Fyansford Formation (Bairnsdalian), Barwon River, near junction with Bruce's Creek, Parish of Murgheboluc, Victoria: A, most of specimen, enlarged, ×4 (L 15.7 mm) and enlargement of sculpture of preradial dissoconch (C ×30, E ×60) and of sculpture near centre of disc (G ×30, H ×33). B, D, F, silicone cast of holotype (natural mould in ironstone) of *Chlamys keiloriana* Crespin, P13466, Green Gully, Keilor, Melbourne, Victoria: B, whole specimen, ×4 (H 15.9 mm); D, F, enlargements of sculpture (D ×40, F ×32) for comparison with Fig. 36G, H.

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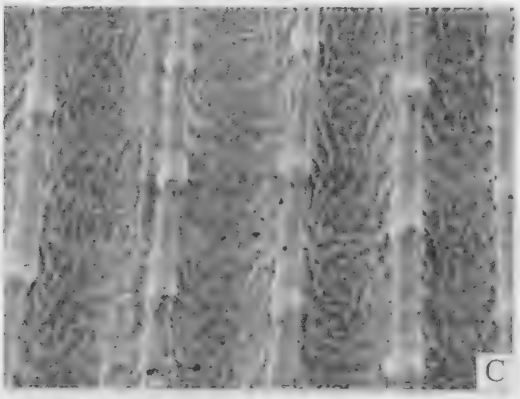
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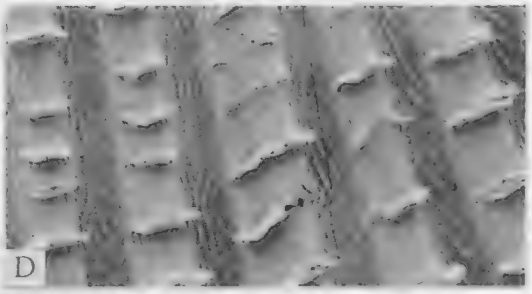
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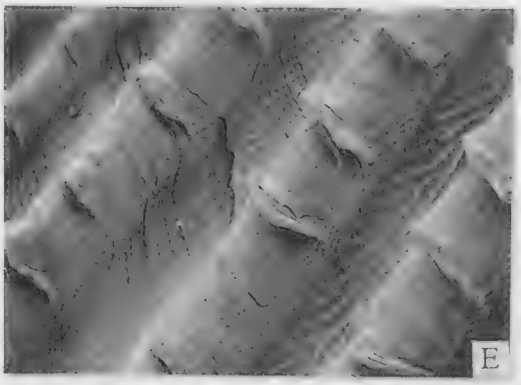
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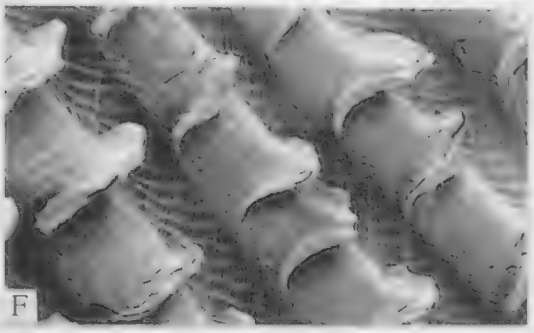
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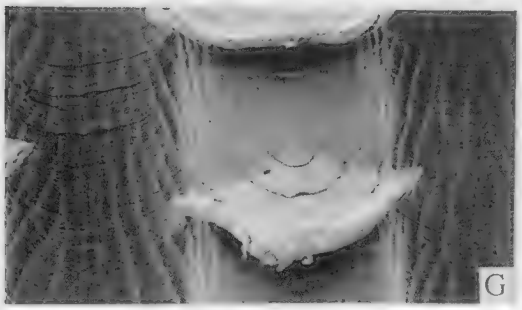
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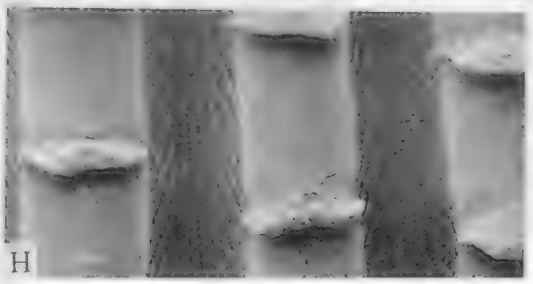

H

c. 30 evenly rounded, rather wide, almost smooth primary costae. Costae essentially are undivided, although a few extra costae are intercalated between the primary ones high on the disc, and costae near the centre of the disc bear one very low, narrow radial ridgelet on the crest of each costa. The intercostal spaces all bear fine, uniform shagreen microsculpture. The auricles both bear several prominent, narrow radial costae, and the anterior one bears prominent commarginal lamellae that are absent from the rest of the shell. This species seems to be most similar to *T. eyrei*, differing in the higher, wider, more closely spaced, and less subdivided costae, and in the more even and consistent shagreen.

Material. WAM 68.975, Pallinup Siltstone (Aldingan), road cutting several miles east of Mt Manypeaks on road to Cape Riche, southern Western Australia, collected by Miss E. Sedgman, January 1968.

C. *Abrakurrie Limestone* (Fig. 38A): A single incomplete RV, 27 mm high, with 22 very high, wide costae of square section, interspaces each equal in width to one costa, low, wide scales on a few costae near the ends of the disc, anterior auricle with deep byssal notch, auricles coarsely sculptured, and all intercostal surfaces (including on auricles) bearing coarse shagreen microsculpture. We have seen nothing else from Australia resembling this specimen.

Material. WAM 66.1407, Abrakurrie Limestone (Longfordian), 10 m below base of Nullarbor Limestone, 8 Mile North Cave, Madura, WA (1 specimen).

D. *Colville Sandstone:* Three very small, abraded, incomplete, recrystallised specimens from Colville Sandstone (Balcombian?, Middle Miocene) are weakly inflated and have a high number (*c.* 58 on smallest specimen and 65 on largest) of very narrow, low, closely spaced radial costae. The specimens are not necessarily all conspecific; the largest and least complete has undivided costae, and very low, thin, commarginal lamellae preserved around the ventral margin are wavy where they cross the costae, suggesting a relationship with *Serripecten*. The other two are RVs with irregularly subdivided costae, low, coarse scales on some costae, and antimarginal ridgelets visible in the intercostal spaces. Little can be said about the relationships of these specimens without better material.

Material. WAM 94.352a–c, Colville Sandstone (Balcombian?), Lake Colville, northern Nullarbor region, WA (three incomplete specimens). Other Colville Sandstone material is referred above to *Semipallium foulcheri*.

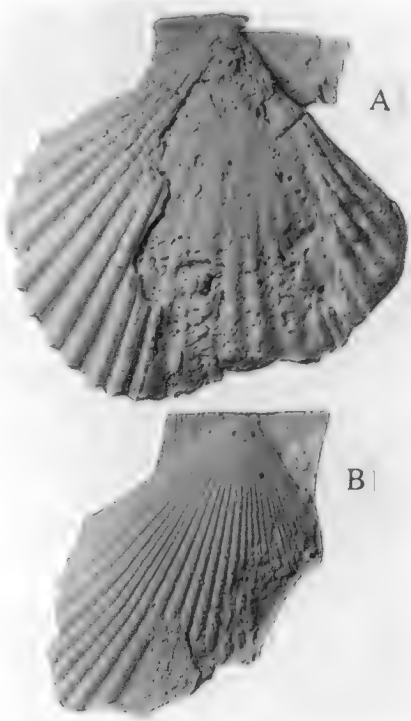
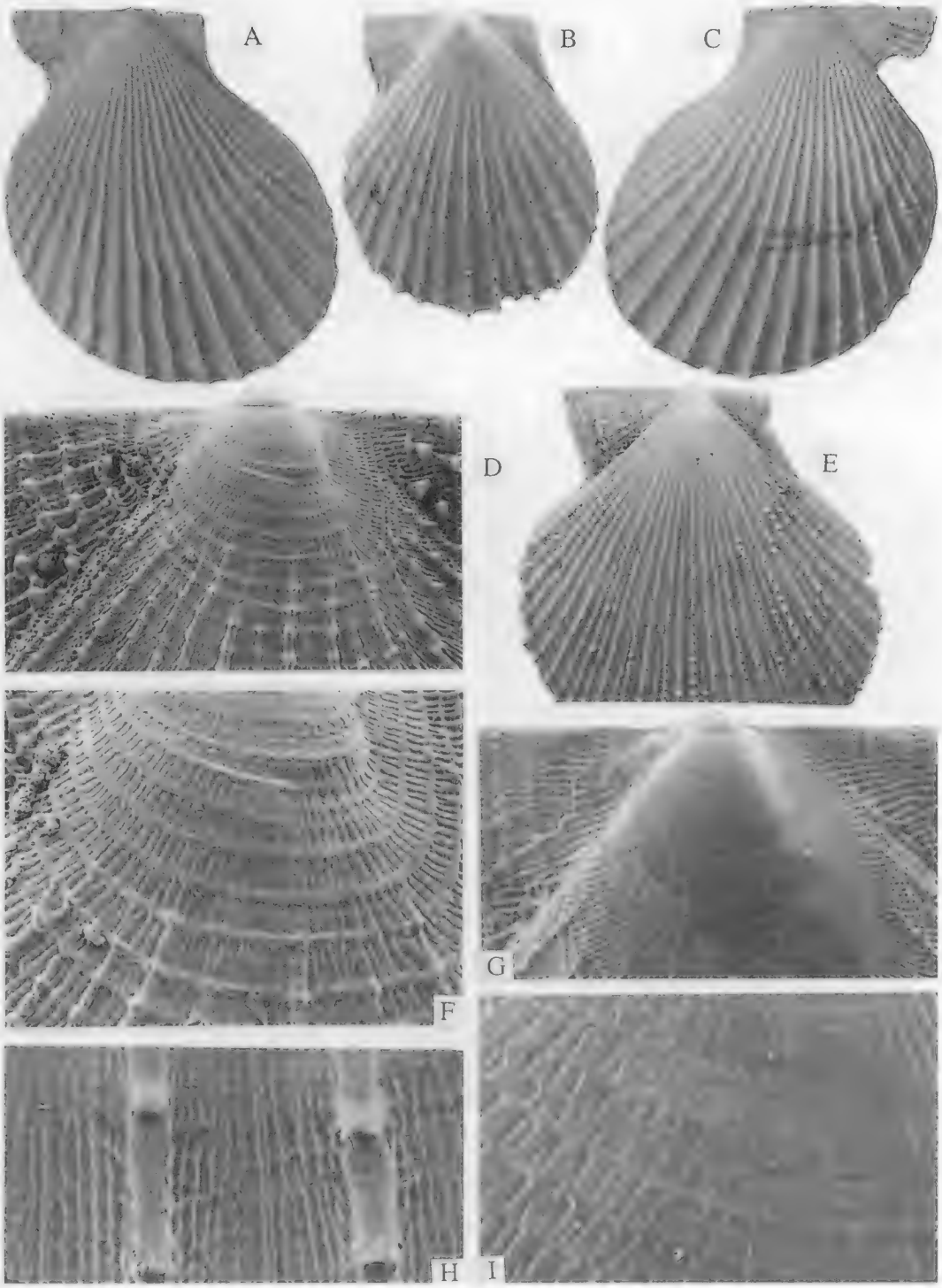


Fig. 38. Two of the unnamed pectinids examined during the preparation of this report. A, *Talochlamys*(?) sp. nov.(?) C, with shagreen between costae; RV, WAM 66.1407, Abrakurrie Limestone (Longfordian), 10 m below base of Nullarbor Limestone in 8 Mile North Cave, Madura, Nullarbor Plain, southeastern Western Australia; enlarged, × 2. B, *Talochlamys*(?) sp. nov.(?) B, silicone impression of natural mould of incomplete RV, WAM 68.975, Pallinup Siltstone (Aldingan), E of Mt Manypeaks on road to Cape Riche, southern Western Australia; enlarged, × 1.25.

Fig. 37. *Talochlamys keiloriana* (Crespin), SEM enlargements of small, incomplete RV, P302138, all data as for Fig. 36A, C, E, G, H. B, whole shell, × 4 (H 18.0 mm). A, C, enlargements of sculpture at costal inception (A × 40) and of early microsculpture (C × 50), and of radiating 'bundles' of antimarginal ridgelets in costal interspaces and the narrow, compound, ventrally curved scales characteristic of this species group (D–F, H × 35, G × 60).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E. *Fyansford Formation:* The beautifully preserved material from Fyansford Formation around Melbourne (Balcombian and, mainly, Bairnsdalian) includes other taxa besides those reported here (*Dichotochlamys dichotomalis*, *Semipallium foulcheri*, *Talochlamys keiloriana*, *Veprichlamys leprosa*, *Mimachlamys sturtiana*, *Annachlamys murrayana*, and *Mesopeplum incertum*). We have seen a few, very small valves only (juvenile?) of what appear to be at least two other taxa: a narrowly costate *Talochlamys*(?) sp. with large, hemispherical, ventrally cupped scales on the radial costae, and another *Talochlamys*(?) sp. resembling *T. keiloriana* but with high, thin, ventrally convex, evenly curved commarginal lamellae in the radial interspaces over the whole shell.

Material. NMV P300419, Fyansford Formation (Bairnsdalian), middle beds at Grice's Creek, near Frankston, Victoria (one LV, with large cupped scales); NMV P301336, all data as above (3 valves with large cupped scales, and one with much smaller scales but with unusually prominent commarginal lamellae).

Other unidentified specimens

In addition to the specimens listed above, three lots of poorly preserved, medium-sized (*c.* 20–30 mm high) chlamydinines with numerous fine, narrow, irregularly subdivided radial costae are present in the NMV collection, but cannot be identified even to genus without better material: (1) BALCOMBIAN, CADELL MARL: PL3084, Cadell Marl lens, 6.4 km S of Morgan, Murray River (1 specimen); (2) BAIRNSDALIAN, BAIRNSDALE LIMESTONE: Princes Highway cutting at Toorloo Arm, Lake Tyers, Gippsland (2 specimens); and (3) CHELTENHAMIAN, BLACK ROCK SANDSTONE: Beaumaris, Mornington, near Melbourne (1 specimen).

Genus *Veprichlamys* Iredale, 1929

Veprichlamys Iredale, 1929a: 164.

Type species (by original designation, Iredale 1929a: 188). *Chlamys perillustris* Iredale, 1925, Recent, deep water off New South Wales.

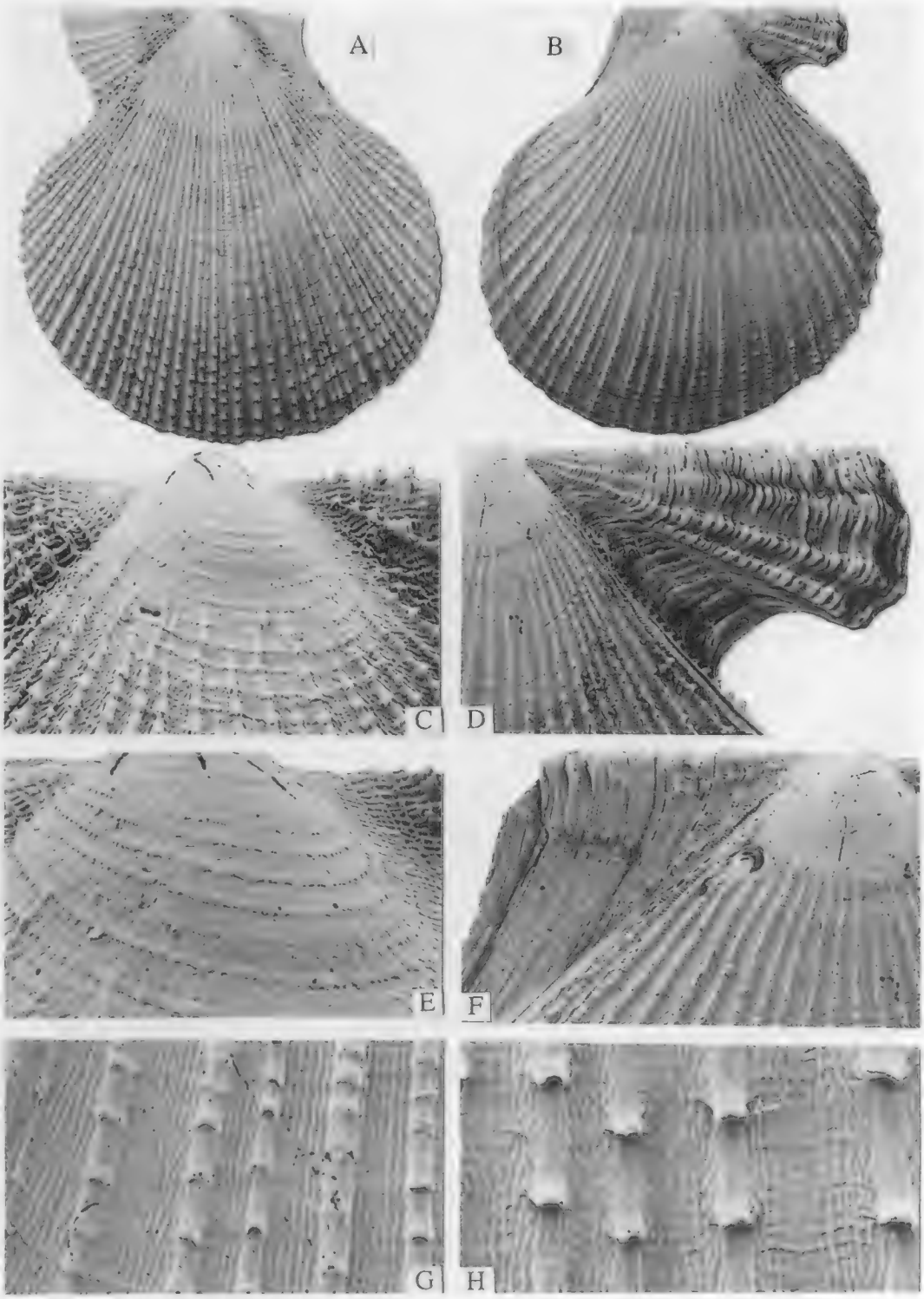
Remarks. Waller (1993: 236) stated that the eastern Pacific species *Chlamys onzola* Olsson (Pliocene, Ecuador) and *C. incantata* Hertlein (Recent, Galapagos Islands) belong in *Veprichlamys*, which can be placed in the Chlamydini 'on the basis of its pre-radial microsculpture and lack of internal rib carinae'. Other distinctive characters of *Veprichlamys*, as displayed by the living eastern Australian type species, *V. perillustris*, in particular, are its tall, narrow, strongly prosocline shape, with a narrow umbonal angle and a long RV anterior auricle, its deep byssal notch and functional ctenolium, its long LV anterior auricle with a strongly sinuous anterior margin and a long, sharply pointed anterodorsal extremity, its short posterior auricles with a concave posterior margin and weak radial sculpture, its disc sculpture of narrow, unusually widely spaced radial costae bearing short, ventrally directed scales, and the intercostal areas being crossed by obvious, very regular antimarginal ridgelets which, in the central few interspaces of the disc, include some ridgelets that are unusually long, straight and continuous. Examination of a juvenile Recent specimen of *V. perillustris* by SEM (Fig. 39A–C, G–I) showed that the LV preradial dissoconch bears microsculpture of rows of short, antimarginally directed grooves, ie., short segments of antimarginal ridgelets, broken up into segments by very low commarginal ridges. The one Australian Cenozoic fossil species assigned here to *Veprichlamys* shares all these critical characters with *V. perillustris*.

Veprichlamys leprosa sp. nov.

Figs 39D–F, 40A–H

Description. Small for genus (to *c.* 20 mm high), relatively short and wide, ie., with wide umbonal angle for genus (*c.* 97–100°); height only slightly greater than length, very weakly inflated, the two valves about equally inflated, shape weakly to moderately prosocline. LV preradial dissoconch sculptured with prominent, narrow, closely spaced antimarginal ridgelets, crossed by narrow, strongly

Fig. 39. A–C, G–I, *Veprichlamys perillustris* (Iredale), type species of *Veprichlamys* Iredale, 1929; Recent, southern Australia: A, C, large adult, AMS C154683, FIS 'Endeavour', 365 m, S of Gabo I., Victoria, October 1914; LV (A) and RV (C) of one specimen, enlarged, × 1.5; B, G–I, SEMs of small juvenile LV, AMS C305945, FIS 'Endeavour' Sta. E4025, 174–183 m, 70 km S of Cape Wiles, South Australia, August 1909; B, whole shell, × 7 (H 6.6 mm), enlargements of sculpture of preradial dissoconch (G × 28, I × 100), and enlargement of intercostal microsculpture near ventral margin (H × 60) to show continuous, straight median antimarginal ridgelet D–F, *Veprichlamys leprosa* sp. nov., paratype, LV, P300420, Fyansford Formation (Bairnsdalian), Grice's Creek, Mount Eliza, Victoria; SEMs of most of small specimen (E × 4, H 14.7 mm) and sculpture of preradial dissoconch enlarged (D × 25, F × 50).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elevated, widely spaced commarginal ridges, forming commarginal zones of short ridgelets. Disc sculpture of *c.* 36–50 narrow, well raised, convex-crested radial costae, increasing irregularly in number down disc, so interspaces remain constant in width on many specimens but increase markedly in width down disc on others; secondary and tertiary costae added by intercalation in centre of interspaces on RV, by both subdivision and a lesser degree of intercalation on LV; all costae bearing many narrow, short to moderately long, ventrally cupped, ventrally directed spines. Radial interspaces closely sculptured with antimarginal ridgelets, some in centre of disc remaining straight and continuous for most or all of disc height. Anterior auricles long; on RV with deep byssal notch, functional ctenolium, wide, deeply sunken byssal fasciole bearing many prominent commarginal ridges, and main face above byssal fasciole sculptured with 4–5 prominent radial costae crossed by very prominent, irregular commarginal lamellae that serrate dorsal margins; on LV tall, with anteriorly sloping, weakly sinuous anterior margin, strongly pointed at anterodorsal extremity, sculptured with 6–9 prominent radial costae as on disc, bearing more prominent spines than on disc. Posterior auricles short, with strongly concave posterior margins, strongly pointed at posterodorsal extremity, sculptured with only 2–4 very narrow, widely spaced radial costae. Interior smooth apart from very weakly sinuous ventral margin. Hinge with long, very narrow dorsal teeth and very short, extremely narrow resilial teeth.

Dimensions.

Holotype, P302793	H	17.0	L 15.8	LV
Figured paratype, NMV P302794		16.3	15.0	RV
Paratype, NMV P302795		19.8	17.2	RV
Paratype, NMV P302796		18.9	18.4	LV
Paratype, NMV P302797		17.6	16.7	LV

Type material. Holotype, NMV P302793, figured paratype, NMV P302794, one paratype, NMV P302795, and 21 other specimens, Fyansford Formation (Bairnsdalian), 'middle beds' at Grice's Creek, Mount Eliza, 8 km south of Frankston, Victoria, coll. F. A. Cudmore, 1940; NMV P302796–7, 2 paratypes and NMV P301357, *c.* 50 other specimens, Grice's Creek, Mount Eliza, 8 km south of Frankston, Victoria, coll. F. A. Cudmore, 1905.

Other material examined. **Balcombian:** FYANSFORD FORMATION: Orphanage Hill road cutting, Fyansford (5 specimens); PL3077, Altona Bay coal shaft (5 specimens). **Bairnsdalian:** FYANSFORD FORMATION: PL3104, Manyung Rocks (2 specimens); Grice's Creek (2 specimens).

Occurrence and time range. Balcombian and Bairnsdalian; limited to Fyansford Formation in the Melbourne district.

Remarks. In most characters, *Veprichlamys leprosa* sp. nov. is a typical species of *Veprichlamys*, the only one we know of occurring fossil in either Australia or New Zealand. It differs from *V. perillustris* in many obvious characters, particularly the much smaller size (*V. perillustris* reaches at least 38 mm in height), the much shorter and wider, less markedly prosocline disc, and the more numerous, more crowded, more frequently subdivided and intercalated radial costae, bearing more numerous spiny scales than in *V. perillustris*. The LV preradial dissoconch sculpture also is markedly more prominent than in *V. perillustris*; although very similar in the spacing of the commarginal ridges and antimarginal ridgelets, the preradial sculpture of *V. perillustris* is much more subdued, and gives the appearance of having been smoothly abraded off. A similar evolutionary series from a more coarsely sculptured LV preradial dissoconch in Miocene species to weaker sculpture in younger species is seen also in *Semipallium*, *Talochlamys* and *Mimachlamys*, indicating that a reduction in the prominence of the earliest sculpture on the LV is a common evolutionary trend in the Pectinidae. Although the antimarginal ridgelets on the central few radial interspaces of the disc of *V. leprosa* are unusually straight and continuous, none is quite as prominent and strictly continuous as in *V. perillustris* (Fig. 39H).

The New Zealand Recent species *Veprichlamys kiwaensis* (Powell) (1933: 371, pl. 40, figs 1–5) was originally collected from a cable hauled up from 'between 600 and 700 fathoms) [*c.* 1025–1280 m], about 650 km west of New Plymouth, ie., presumably on the Challenger Plateau. This species has since proved to be quite common around New Zealand in moderate depths, and many lots in the Museum of New Zealand Te Papa Tongarewa were compared with *V. perillustris* and *V. leprosa*

Fig. 40. Veprichlamys leprosa sp. nov., SEMs of holotype and paratype, Fyansford Formation (Bairnsdalian), Grice's Creek, Mount Eliza, Victoria. A, C, E, H, holotype, LV, P302793, whole shell, × 4 (H 16.8 mm), and enlargements of sculpture of preradial dissoconch (C × 30, E × 60) and of microsculpture near ventral margin (H × 28). B, D, F, G, paratype, RV, P302794, whole shell, × 4 (H 16.2 mm), and enlargements of auricles (D × 12, F × 16) and of microsculpture near ventral margin (G × 22).

sp. nov. In general appearance *V. kiwaensis* is more similar to *V. perillustris* than *V. leprosa*, as like *V. perillustris* it consistently has very narrow, widely spaced, prominent radial costae with long, narrow, semitubular, ventrally directed spines on the costal crests, and with only minor bifurcation and intercalation of secondary costae, rather than having the many, fine closely spaced, secondary radial costae that are present on *V. leprosa*. *V. kiwaensis* reaches a slightly smaller maximum size, is much less strongly prosocline, is slightly more inflated, and has a significantly shorter RV anterior auricle and a shorter, much taller and straighter anterior margin to the LV anterior auricle than in *V. perillustris*. In most characters, then, *V. leprosa* sp. nov. actually is nearer to *V. kiwaensis* than *V. perillustris*, differing from *V. kiwaensis* in its smaller size, its still less markedly prosocline shape, its longer and more sinuous anterior margin to the LV anterior auricle, and its much more numerous secondary radial costae. The sculpture of the LV preradial dissoconch of *V. kiwaensis* has the same prominent, sharp commarginal ridges crossing relatively prominent antimarginal ridgelets as occurs in *V. perillustris* (Fig. 39D, F), and the antimarginal ridgelets in the costal interspaces over the central part of the disc of *V. kiwaensis* are long, parallel and straight as in *V. perillustris*.

In its longer and wider shape, its much less strongly prosocline disc, its longer posterior auricles and its taller but more weakly sinuous-margined LV anterior auricle, the adult of *V. leprosa* resembles the juvenile stage of *V. perillustris*. This suggests the possibility that *V. perillustris* (and possibly also *V. kiwaensis*) evolved from *V. leprosa* by a heterochronic process (McKinney & McNamara 1991).

As far as we are aware, this is the first published record of a pre-Pliocene species assigned to *Veprichlamys*.

Etymology. The specific name (Latin, '*leprosus*', literally leprous, or scaly) refers to the fine scaly sculpture of this species.

Genus ***Zygochlamys*** Ihering, 1907

Zygochlamys Ihering, 1907: 250.

Type species (by original designation). *Pecten geminatus* Sowerby, 1846, San Julian Formation (Late Eocene–Early Oligocene), near Puerto Madryn, Argentina.

Remarks. In the opinion of Dr Waller (1999, pers. comm.) and Dr Jonkers (1999, pers. comm.) the circum-Antarctic Plio-Pleistocene and circum-Subantarctic Recent species usually included in *Zygochlamys* are not closely related phylogenetically to the South American fossils. However, a large collection of *Z. geminata* (Sowerby) from San Julian Formation (Gran Bajo de San Julian, Argentina; IGNS, 30 specimens) is very similar to the Pliocene to Recent species, indicating that the latter are direct descendants of *Z. geminata*. We consider *Chlamys delicatula* (Hutton) to be correctly included in *Zygochlamys*.

Dell (1964: 180) and Beu (1985) pointed out the synonymy of *Chlamys instar* Iredale with *Zygochlamys delicatula* (Hutton), the very abundant Late Pliocene to Recent cold-water indicator species in New Zealand. However, the Late Pleistocene occurrences of *Z. delicatula* as empty valves on the shelf off southern New South Wales and southeastern Tasmania provided the sole records of this genus in Australia.

As used here, the genus *Zygochlamys* is characterised by its relatively large size for a chlamydoid chlamydinine (*Z. delicatula* reaches *c.* 100 mm high; South American–Antarctic Peninsula fossils reach *c.* 120 mm), its rather tall, narrow shape (ie., narrow umbonal angle) in all but the largest adults, its loss of byssal attachment and consequent shallowing of the byssal notch in large adults of at least the Pliocene to Recent species, which lie free on the seabed, its consistent LV radial sculpture of narrow, widely spaced radial costae with wide, shallowly and evenly concave interspaces, each bearing numerous secondary and tertiary costellae margining the primary costae in a fasciculate pattern, the very numerous, fine, low, ventrally directed scales on all secondary and tertiary costellae, and the LV preradial dissoconch microsculpture of simple antimarginal ridgelets (Fig. 43A, C, E), which continue across the whole shell and are obvious in the radial interspaces of even the largest adults. The simple antimarginal LV preradial sculpture demonstrates that this is a primitive chlamydinine, phylogenetically related to *Chlamys, sensu stricto*.

Zygochlamys delicatula (Hutton, 1873)

Fig. 41A–G

Pecten delicatula Hutton, 1873: 30.

Chlamys asperrimus [*sic*]; Hedley & May, 1908: 113 (not *Pecten asperrimus* Lamarck, 1819).

Chlamys antiaustralis; Hedley, 1911: 96 (Cape Pillar record only); May, 1921: 44; May, 1923, pl. 3, fig. 8 (not *Pecten antiaustralis* Tate, 1886).

Pecten (Patinopecten) delicatulus; Suter, 1914: 42, pl. 9, fig. 4.

Chlamys subantarctica Hedley, 1916b: 23, pl. 2, figs 14, 15; Tomlin, 1948: 230.

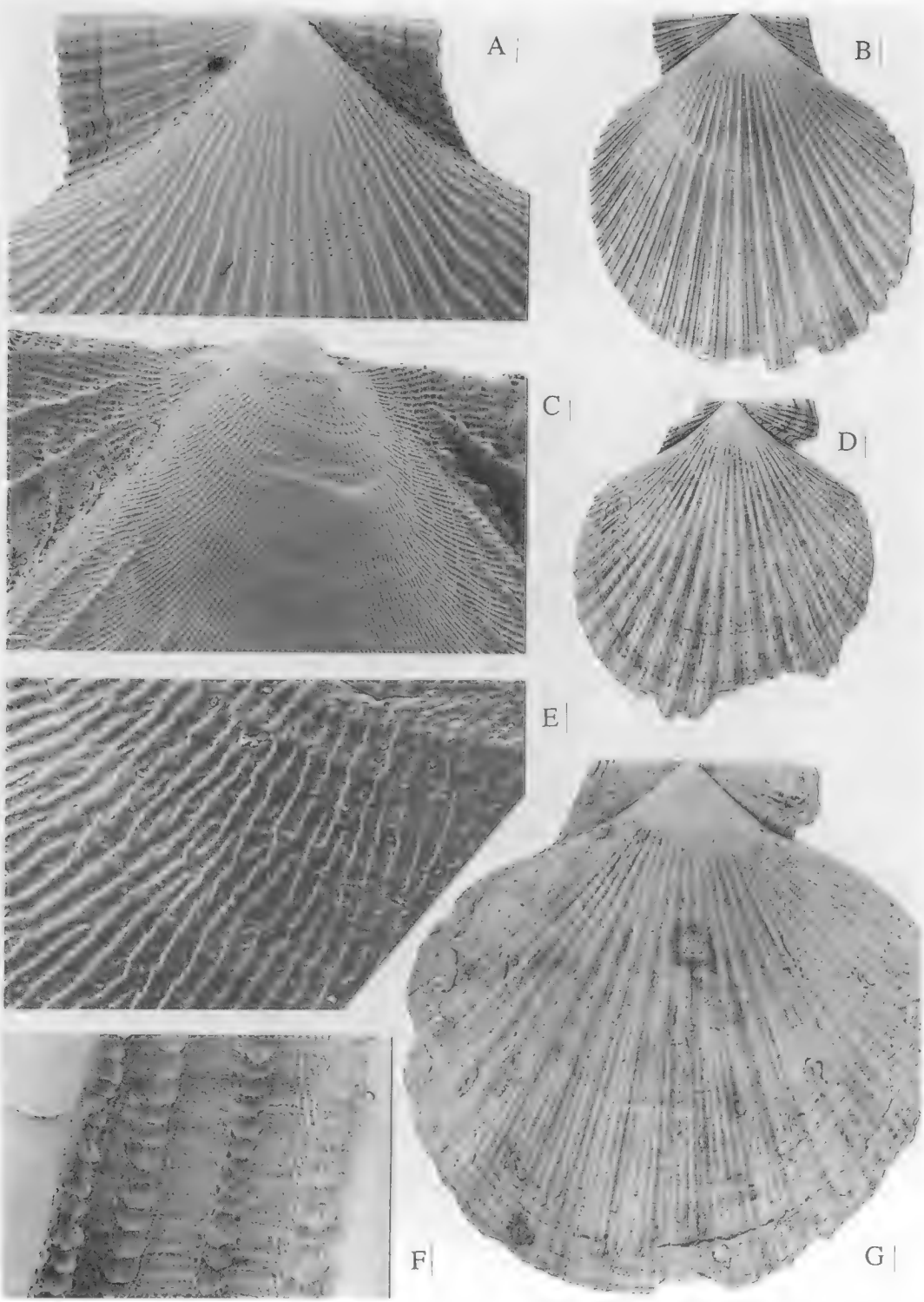
Pecten delicatulus; Thomson, 1919: 282.
Chlamys campbellicus [*sic*] Odhner, 1924: 61, pl. 2, fig. 36 (only); Powell, 1939: 222, pl. 50, figs 10–14.
Chlamys instar Iredale, 1925: 251, pl. 41, figs 5–7.
Chlamys titirangiensis Marwick, 1928: 458, fig. 28.
Chlamys delicatula; Marwick, 1928: 453; King, 1933: 353; Fleming, 1944: 210; Boreham, 1963: 3–25; Beu, 1977: 199–203; Fleming, 1979: 72, fig. 72c, d; Fleming, 1980: 20, fig. 5.
Chlamys campbellica; Fleming, 1944: 209.
Chlamys (Zygochlamys) delicatula; Powell, 1950: 76; Powell, 1955: 25; Dell, 1956: 19; Fleming & Boreham in Pantin, 1957: 788, figs 1, 2; Powell, 1960: 175; Pantin, 1963: 507, figs 1, 3, 4; Dell, 1964: 180; Boreham, 1965: 22, pl. 5, figs 8–10; Beu et al., 1977: 217–234, figs 3–6; Powell, 1979: 379, pl. 68, fig. 3; Beu et al., 1981: 126–132.
Mimachlamys instar; Kershaw, 1955: 294.
Chlamys (Zygochlamys) instar; Dell, 1964: 180.
Chlamys patagonica delicatula; Beu, 1985: 4, pl. 1, figs 5–9; pl. 2, figs 1–5; Beu & Maxwell, 1990: 308. pl. 38j; Lamprell & Whitehead, 1992, pl. 9, fig. 48.
Chlamys (Mimachlamys) instar; Rombouts, 1991: 29.
Zygochlamys delicatula; Waller, 1991: 28–29, pl. 3. fig. 4; Beu, 1995: 15, figs 3a–d, 23b, c, e.

Description. Moderately large (to *c.* 100 mm and, rarely, to 110 mm high), weakly to moderately prosocline, moderately inflated, LV weakly to markedly more inflated than RV in most specimens; umbonal angle very low in juveniles (*c.* 85–90°) which are therefore unusually tall and narrow, increasing to *c.* 115–120° in adults, in which length exceeds height in some specimens. Exterior sculpture of *c.* 25–28 moderately prominent radial costae, on RV relatively wide, crests smooth on most specimens, developing secondary and then tertiary threads alongside each costa across the disc by subdivision to produce a very regular fasciculate rib profile on almost all specimens, and low secondary and tertiary costellae intercalated in interspaces occupying most of interspace width; on LV, primary costae lower and narrower than on RV, low secondary and tertiary costellae filling each gently and evenly concave interspace; all costal crests other than primary ones bearing very many low, wide, closely spaced, ventrally directed scales. Radial interspaces closely sculptured with fine commarginal lamellae, minutely frilled by fine, even, antimarginal ridgelets in a characteristic, distinctive pattern. RV anterior auricle long, with deep, narrow functional byssal notch and ctenolium in juveniles, not functional in adults, which have a shallow byssal notch of evenly concave outline; LV anterior auricle high, with weakly and evenly convex posterior outline, sloping weakly towards anterior; anterior auricles short, high, sloping strongly towards anterior, with weakly concave posterior outline. Interior weakly corrugate. Hinge with quite prominent, narrow dorsal and resilial teeth in RV of large specimens, and correspondingly obvious sockets and infradorsal ridges in LV.

Type material was listed by Beu (1995: 17) and need not be repeated here.

Material examined. *Chlamys instar* Iredale, 1925, holotype and 9 paratypes, AMS C29103, dredged in 180 m, 11 km east of Cape Pillar, SE Tasmania, by Hedley & May (1908); 3 other juvenile LVs with same data and reg. No., 'pres. C. Hedley'; AMS C115202, BMR sta. S73-1984, NE of Cape Pillar, SE Tasmania, coll. P. H. Colman on MT 'Sprightly', 13.iii.1973 (5 valves); AMS C108843, FRV 'Kapala' sta. K77-10-17/18, SE of Gabo Island, Victoria, 220 m, 20.vii.1973, coll. K. J. Graham (1 LV); AMS C110804, FRV 'Kapala' sta. K77-01-13/15, east of Gabo Island, Victoria, 220 m, coll. K. J. Graham, 21.iii.1977 (2 RV, 2 LV); AMS C122923, FRV 'Kapala' sta. K79-17-01, east of Eden, NSW, coll. K. J. Graham, 24.x.1979 (1 LV); AMS C97427, 140 m, off Cape Raoul, southern Tasmania, ex T. A. Garrard coll. (1 LV); AMS C110809, FRV 'Kapala' sta. K77-17-01/2, east of Twofold Bay, NSW, 274 m, coll. K. J. Graham, 12.x.1977 (1 LV); AMS C98623, 4 km east of Tasman Island, SE Tasmania, 183 m, coll. W. F. Ponder on FRV 'Penghana', 24 March 1970 (one RV fragment); AMS C110731, FRV 'Kapala' sta. K77-17-08/9, east of Gabo Island, Victoria, 220 m, coll. K. J. Graham, 13.x.1977 (7 RV, 4 LV); AMS C125077, FRV 'Kapala' sta. K79-17-17, off green Cape, SE NSW, 157–154 m, coll. K. J. Graham, 29.x.1979 (1 large LV, yellow interior, H 95.0, L 93.1 mm).

Remarks. The generic characters listed above, and particularly the LV sculpture of narrow, widely spaced radial costae with wide, shallowly concave interspaces filled with numerous scaly secondary and tertiary costellae, and the shallowing of the byssal notch in adults, distinguish this species readily from all other Australian pectinids. Specimens dredged from the continental shelf off eastern Tasmania and off southeastern New South Wales were confused with *Mimachlamys asperrima* (or its synonym *M. antiaustralis*) by Hedley & May (1908), Hedley (1911) and May (1921), but *M. asperrima* differs (among other, subtler characters) in its greater inflation, in its smaller size, in having a fixed number of undivided costae, and in retaining a deep byssal notch in adults. Iredale (1925: 251) recognised that the records now referred to *Z. delicatula* indicated a different species, and named it *Chlamys instar*. Beu (1995: 15–16) gave a full account of the synonymy and of the range and significance of this species in New Zealand. Young fossils have since been found off the far north of New Zealand, off the Three Kings Islands and northeastern North Island (Beu 1999) and it is clear that this species extended its range at least 600 km north of the present one during the Last Glacial Maximum. However,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Z. delicatula has not been found in the late Cenozoic rocks of southern Australia, suggesting that sea temperatures never fell as low around southern Australia during Late Pliocene and Early Pleistocene time as they did around New Zealand.

Beu (1985) cited a ^{14}C date of 19 000 years BP for specimens of *Z. delicatula* from off Cape Pillar, southeastern Tasmania, demonstrating that the Australian records date from the Last Glacial Maximum. The empty shells on the shelf of southeastern Australia are thus very young fossils, and deserve including here. Beu (1995) listed all the type material, and the other necessary data for this species in New Zealand (including 125 localities for Late Pliocene fossils in eastern North Island). The object here is to list the known localities for Last Glaciation Maximum records in Australia, and readers are referred to Beu (1995) for other details of this species. It is noteworthy that only 10 lots (*c.* 40 specimens) are listed above from Australia, and all were collected in one of two small areas: (a) six lots are from the Twofold Bay–Gabo Island area, near the NSW–Victoria border, and (b) four lots are from off southeastern Tasmania. There are no intermediate records from Bass Strait.

Tribe Adamussiini Habe, 1977

Remarks. A diagnosis of the tribe is provided above, under 'Classification'. The tribe Adamussiini is adopted here to include the superficially smooth, *Amusium*-like pectinids lacking internal rib carinae that occur in Eocene to Miocene rocks of Australia and New Zealand. It includes also the closely related Antarctic genus *Adamussium* Thiele, 1934, which has been reported so far from Oligocene to Pleistocene rocks and in the living fauna. The generic content of the tribe in Australia and New Zealand is discussed below. Distinctive characters of the tribe are the moderate size, the weak inflation, the nearly circular disc, the sculpture almost entirely of weak, fine antimarginal ridgelets, present at least on the auricles and the anterodorsal and posterodorsal disc areas of all taxa, the obvious radial costae on the RV anterior auricle (at least, early in ontogeny), the almost equal auricles, the serrate RV dorsal margins, the shallow byssal notch in adults but deeper byssal notch and, in most (presumably all) taxa, functional ctenolium in juveniles, the radial sculpture which, if present, develops late in ontogeny and in many taxa is expressed differently on the two valves, and the obvious, widely separated gill-suspensor muscle scars on the RV interior, ventral to the adductor muscle scar. The European Eocene genus and species *Pseudentolium corneum* (J. Sowerby, 1818: 1, pl. 204) is not a member of the Adamussiini, as it lacks the serrate RV dorsal margins and the obvious RV gill-suspensor scars, it lacks all signs of radial sculpture on the RV anterior auricle, it has less well developed disc flanks, and the auricles are significantly different in shape, with a more semicircular RV anterior auricle outline and a RV posterior auricle posterior outline that is less convex and more oblique to the hingeline than in *Victoripecten* and other members of Tribe Adamussiini (Dr T. R. Waller 1999, pers. comm.).

Genus ***Victoripecten*** gen. nov.

Type species. *Lentipecten victoriensis* Crespin, 1950, Late Eocene to Early Miocene, southern Australia.

Diagnosis. Moderate-sized, weakly inflated, almost circular Adamussiini with weak radial sculpture on proximal area of RV anterior auricle, otherwise sculptured only with antimarginal ridgelets; with almost equal auricles, and only a shallow byssal notch remaining in adults, but a deeper notch and functional ctenolium present in specimens up to half-grown; dorsal margins of RV auricles serrated by growth ridges; weak, low radial costae developing late in ontogeny on RV posterior auricles (at least, in some specimens); several small, obvious, widely separated, deeply impressed gill-suspensor muscle scars present in the RV interior ventral to the adductor muscle scar.

Remarks. The Australian species for which *Victoripecten* is proposed has been included previously in *Lentipecten* Marwick, 1928 (type species: *Pecten hochstetteri* Zittel, 1864, Late Oligocene,

Fig. 41. *Zygochlamys delicatula* (Hutton). A, C, E, F, IGNS R5835, SEMs, Recent, Portobello Marine Biological Station Sta. Mu 67–118, 420 m, Saunders Canyon, off East Otago, South Island, New Zealand: A, umbonal area and auricles of small LV, enlarged, × 5.6 (hinge length = 10.3 mm); C, E, sculpture of preradial dissoconch enlarged, × 37 and × 150, showing simple antimarginal ridgelets typical of primitive Chlamydini; F, sculpture near ventral margin, enlarged, × 30, showing antimarginal ridgelets on scales and interspaces (from Beu 1995). B, D, G, paratypes of *Chlamys instar* Iredale, AMS C29103, from 180 m, off Cape Pillar, SE Tasmania, young 'fossils' of Last Glacial Maximum age; B, LV; D, G, RVs; all at natural size.

New Zealand). The homeomorphy among these essentially smooth, saucer-shaped scallops, resembling *Amusium* externally but lacking internal rib carinae, is the most marked of all Australasian pectinid groups. During Eocene to Late Miocene times, when warmer than present sea temperatures prevailed around New Zealand and southern Australia, there was obviously very strong selection pressure by predators, driving scallops towards losing radial sculpture and becoming rapid, efficient swimmers (see 'paradigms' section in Johnson 1984). The *Lentipecten* shell form evolved repeatedly during this time, to the extent that many of the homeomorphs have been confusing and impossible to resolve until origins and time ranges were determined. The homeomorphs of *Lentipecten* in Australia and New Zealand are:

1. True *Lentipecten hochstetteri* (Zittel, 1864), the type species of *Lentipecten* Marwick, 1928; this is a Late Oligocene (Duntroonian) species of relatively large size (to at least 95 mm high) with strongly serrated RV auricle dorsal margins, an almost circular shape to slightly longer than high, and a hinge with very prominent dorsal teeth and the resilial teeth relatively long but very narrow and diverging at a much wider angle than in the Miocene 'aff. *Lentipecten*'; apparently descended from *Janupecten subteres* (Marwick) by loss of its very weak radial sculpture (so *Janupecten* Marwick, 1928 is a synonym of *Lentipecten* Marwick, 1928; as first revisers, we select *Lentipecten* Marwick, 1928 as the valid name to be used by all authors who consider that *Lentipecten* Marwick, 1928 and *Janupecten* Marwick, 1928 are synonyms). Examination of Zittel's (1864: pl. 11, fig. 5a) figured LV syntype of *L. hochstetteri* in Naturhistorisches Museum Wien (NHMV 1959/335/41) showed that this interpretation of the species is correct (seen, AGB, June 1998).

2. The Late Oligocene–Late Miocene 'aff. *Lentipecten* sp. nov.' of Maxwell (in Beu & Maxwell 1990: 144–145, pl. 10c, d), the species traditionally identified as *L. hochstetteri*, which is smaller (reaching *c.* 85 mm in height), is slightly taller than long, has only weakly serrate RV auricular dorsal margins, and has a hinge with the dorsal teeth a little less prominent than in *L. hochstetteri*, and with the resilial teeth much shorter and more steeply inclined than in *L. hochstetteri*. The origins of this species are unclear, but as some similar specimens are known from Oligocene rocks (ie., coeval with *L. hochstetteri*) it cannot have descended from *L. hochstetteri*; possibly it descended from '3.', below.

3. A Bortonian (Middle Eocene) close homeomorph of the Oligocene–Miocene 'aff. *Lentipecten*', from the upper Waihao River, South Canterbury (P. A. Maxwell, pers. comm.); much smaller than the Oligocene–Miocene specimens (to *c.* 50 mm high, rather than 85 mm).

4. *Duplipecten* Marwick, 1928; Maxwell (in Beu & Maxwell 1990: 101, pl. 5d; Maxwell 1992: 64–65, pl. 3d–f) demonstrated that the late Middle and Late Eocene species *D. parki* (Marwick, 1942), although included in *Lentipecten* by Marwick (1942), is not a particularly close homeomorph of *Lentipecten*. It has the opposite relative valve inflation to *L. hochstetteri*, the auricles are set off from the disc by deep, undercut grooves, quite unlike the very shallow, obscure grooves of other *Lentipecten* homeomorphs (including *Victoripecten*), the proximal part of the disc, in particular, is sculptured with fine but obvious, regular commarginal ridgelets, and the hinge has a very different appearance as the teeth are much less obvious than in *Lentipecten* and the interior of the dorsal margin is dominated by large, thick, valve-abutting surfaces. *D. parki* is apparently descended from the slightly earlier Bortonian *D. waihoaensis* (Suter), which has obvious, low, wide radial costae developing relatively late in ontogeny on the LV disc.

5. '*Lentipecten* with a ctenolium'; a collection from the Bortonian (Middle Eocene) Island Sandstone at 10 Mile Bluff, north of Greymouth, Westland, New Zealand (IGNS, GS2600, GS2873) contains a few small specimens (to *c.* 45 mm high) that resemble *Lentipecten* in most characters (ie., in the lack of most pectinid characters!) but have a deeper byssal notch and retain a functional ctenolium in the largest specimens. No other specimens of these homeomorphs have been observed in New Zealand that bear a ctenolium, other than in small juveniles.

6. *Victoripecten* gen. nov., proposed here for Australian shells resembling the New Zealand *Lentipecten* homeomorphs listed above. *Victoripecten* resembles a larger version of homeomorph '5.', as small (immature?) specimens from Late Eocene (Aldingan) rocks near Adelaide retain a functional ctenolium in the largest specimens seen, and younger, larger specimens have ctenolial teeth preserved in the groove between the RV anterior auricle and the disc until about half the adult size. Whether these might really be related phylogenetically to the New Zealand Middle Eocene species or were derived independently is unclear.

Whatever the relationships of *Victoripecten*, it is clear that its resemblance to *Lentipecten* is superficial, if nothing else because it appeared in Australia before the real *Lentipecten* had evolved in New Zealand, and the Australian species with an Eocene (Aldingan) to Early Miocene (Batesfordian) time range and with a functional ctenolium until at least half adult height belongs in a genus distinct from *Lentipecten*. Indeed, one should obviously be highly sceptical of the placement of any extra-New Zealand taxa in *Lentipecten*. Even in New Zealand, the limits and relationships of *Lentipecten* are complex, and any superficially similar taxa from the Northern Hemisphere are highly likely to be yet more unrelated homeomorphs.

Victoripecten is proposed here, therefore, for the Australian species *Lentipecten victoriensis* Crespin, 1950. Despite the obvious impossibility of the Late Eocene to Early Miocene *V. victoriensis* having anything to do with the Late Oligocene *Lentipecten hochstetteri* in any phylogenetic sense, the only characters distinguishing *V. victoriensis* from *Lentipecten hochstetteri*, *sensu stricto* are its smaller size (to *c.* 70 mm high), the presence of a few very weak, faint radial costellae on the RV posterior auricle and on the anterior and posterior margins of the disc on some specimens, its rather more rounded (almost subcircular, rather than triangular) resilifer, its slightly longer and more steeply inclined resilial teeth, and the presence of a functional ctenolium until about half adult size. Complete specimens certainly resemble the near-circular shape of *L. hochstetteri*, *sensu stricto* rather than the slightly taller shape of the Miocene 'aff. *Lentipecten*'.

Etymology. The generic name (Victoria + *Pecten*) refers both to the state in which the holotype of the type species was collected, and to the name of the type species. Gender masculine.

Victoripecten victoriensis (Crespin, 1950)

Figs 42A–E, 43A–F

Pecten pleuronectes; Tenison Woods, 1865: 1, fig. 5 (not *Ostrea pleuronectes* Linné, 1758).

Pecten hochstetteri; Tate, 1886: 114 (not *P. hochstetteri* Zittel, 1864).

Lentipecten victoriensis Crespin, 1950: 151, pl. 15, figs 8–11.

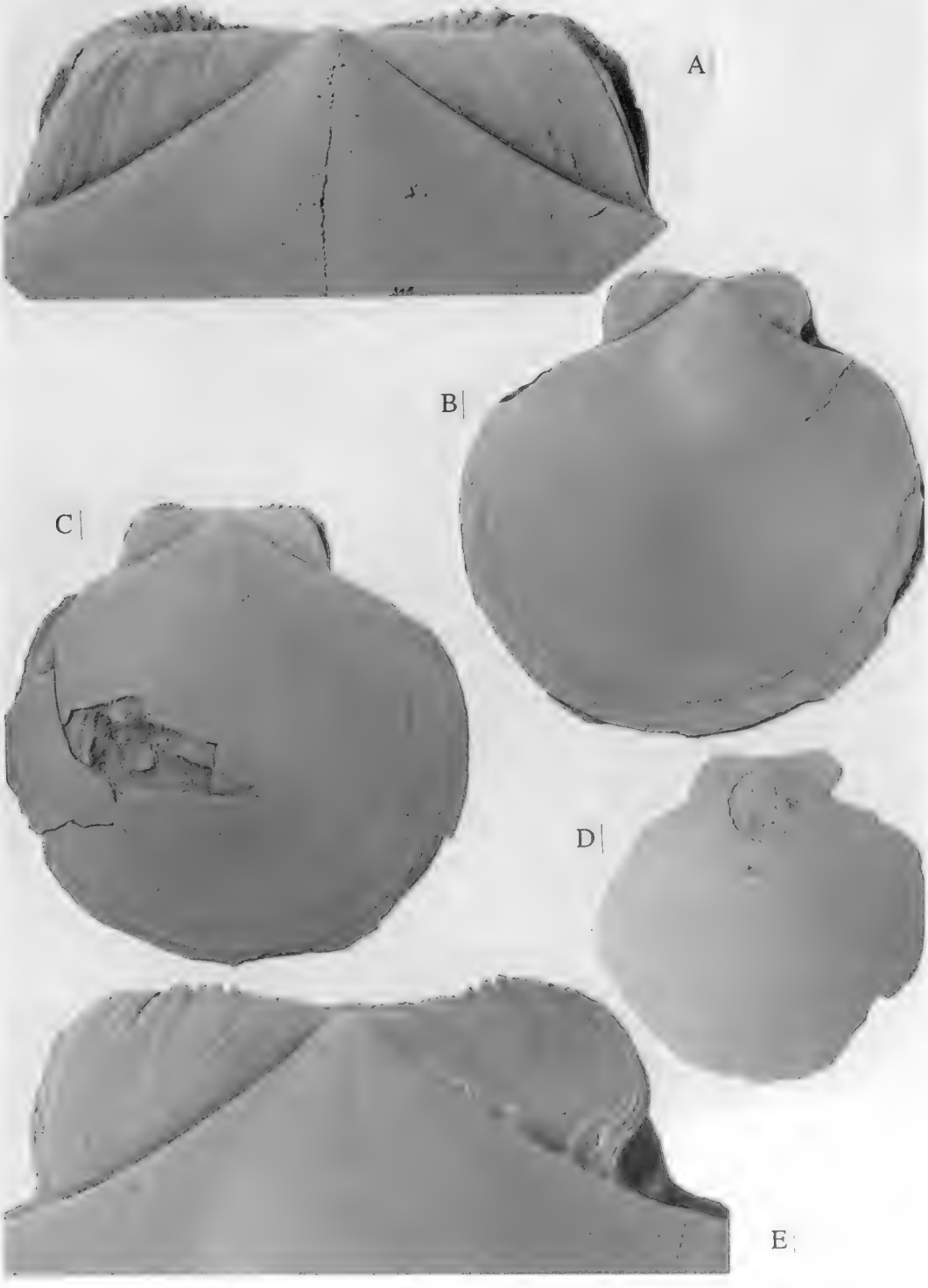
Description. Moderate-sized (Janjukian–Batesfordian adults to *c.* 70 mm high), equidimensional, ie., acline to weakly prosocline and subcircular, weakly inflated; umbonal angle moderately wide (120–125°); valves gaping slightly at anterior and posterior ends. Exterior essentially smooth, with faint commarginal corrugations; very faint, low radial costellae develop near the anterodorsal and posterodorsal disc margins RV of some specimens, but are absent from others; RV anterior auricle with 4–6 low radial costae on proximal area, fading out over distal area; RV posterior auricle developing weak, low, vague radial costae late in ontogeny in some specimens; entire surface bearing fine anti-marginal ridgelets. RV anterior auricle retaining moderately deep byssal notch and functional ctenolium to about half adult size, not functional in Janjukian–Batesfordian adults; adults retaining shallow, concave byssal notch, auricle outline strongly and evenly convex above notch; posterior auricle weakly to quite strongly convex in outline, sloping slightly dorsally towards anterior; LV auricles symmetrical, with weakly convex outlines, both ends sloping dorsally in towards umbo; dorsal margins of both RV auricles weakly to moderately strongly serrate, spines narrow, triangular and closely spaced on most specimens. Interior lacking internal rib carinae, but with obvious adductor scar, and in RV several (3–4 in most specimens) obvious, deeply impressed, widely separated gill-suspensor muscle scars in central aragonite layer ventral to adductor scar. Hinge with long, narrow, prominent dorsal teeth in RV and corresponding sockets and infradorsal ridges in LV, but very weak, low resilial teeth.

Dimensions.

Holotype of *Lentipecten victoriensis*	H 69.7	L 69.7	2 valves
NMV P302195, Waurn Ponds	68.4	67.7	RV
NMV P302196, Waurn Ponds	57.8	58.1	LV
NMV P302197, Waurn Ponds	52.1	48.1	RV

Type material. Holotype of *Lentipecten victoriensis* Crespin, 1950, CPC F16098, from 300 m ['1000 feet'] in the Lakes Entrance oil shaft, Gippsland, Victoria, Janjukian, coll. I. Crespin, 1945.

Other material examined. **Aldingan:** BLANCHE POINT FORMATION: PL3010, Blanche Point (1 specimen); 18–23 m in Clinton Bore No. 1, Clinton, SA (1 specimen); WAM 94.199, Port Noarlunga (4 specimens); WAM 94.269, Maslin beach (1 specimen); PORT WILLUNGA FORMATION: PL3297, Onkaparinga River mouth (1 specimen); TORTACHILLA LIMESTONE: PL3464, Tortachilla Trig (7 specimens); MULOOWURTIE FORMATION: PL3617, S of Muloowurtie Pt (3 specimens); PL3282, S of Ardrossan (13 specimens); ROGUE FORMATION: PL3284, S of Port Julia (4 specimens). **Janjukian:** CALDER RIVER LIMESTONE: Aw3 and Aw4, Aire coast (12 specimens); Aw3, Aire coast (29 specimens); Aw4, Aire coast (2 specimens);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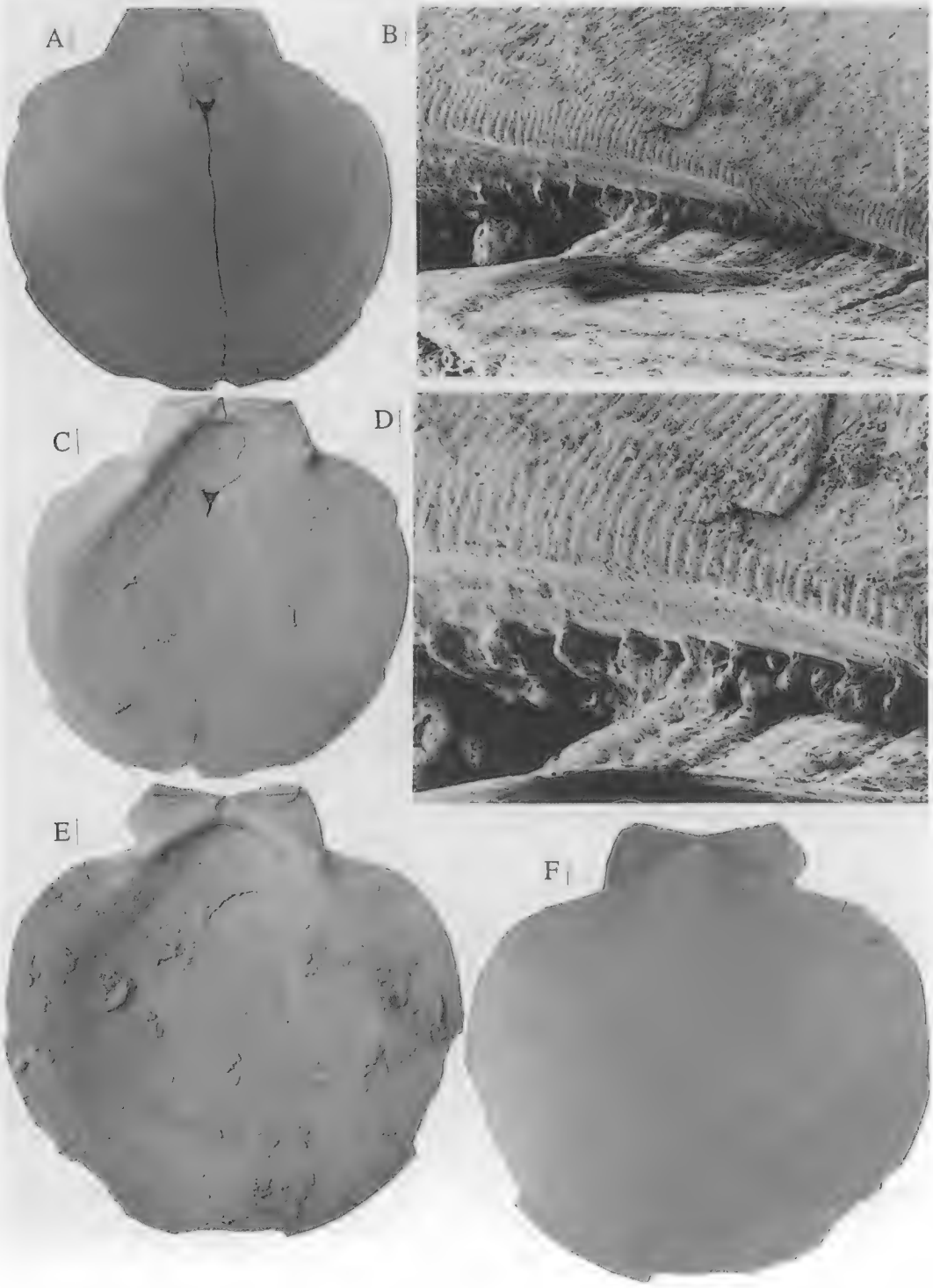
Spud Point, Glen Aire (2 specimens); Calder River (9 specimens); small quarry, left bank Calder River, N of Horden Vale (4 specimens); CLIFTON FORMATION: Alkemade's Quarry, Kawarren (4 specimens); base of limestone overlying conglomerate, 0.8 km NW of Point Ronald, Princetown (15 specimens); JAN JUC FORMATION: PL3024, Bird Rock (12 specimens); PL3025, Fishermans steps, Torquay (6 specimens); between PL3024 and PL3025 (5 specimens); Spring Creek, Torquay (19 specimens); Torquay (3 specimens); AMS F2014, Jan Juc, 26 km S of Geelong (1 specimen); PORT WILLUNGA FORMATION: PL3292, Wool Bay (2 specimens); PL3293, Stansbury (2 specimens); cliff S of Jetty, Port Willunga (1 specimen); WAURN PONDS LIMESTONE: Waurn Ponds (49 specimens); cutting N side Cochrane's Rd, 6.4 km N of Princes Highway (1 specimen); marl over limestone, quarry near railway line, Waurn Ponds (1 specimen); Harris Quarry, Waurn Ponds, Geelong 345 872 (11 specimens); new quarry, Waurn Ponds (10 specimens). **Longfordian:** FOSSIL BLUFF SANDSTONE: PL3029, Fossil Bluff (5 specimens); GAMBIER LIMESTONE: PL3230, ACI lime quarry (12 specimens); PL3231, quarry, Donovan's Rd (10 specimens); PL3235, Gambier Earth Movers quarry (103 specimens); PL3240, quarry, Settlers Rd (1 specimen); PL3244, council quarry, Smith's property, Port MacDonell (2 specimens); Mount Gambier (5 specimens); SANDFORD LIMESTONE: PL3161, quarry, Runnymede Rd (2 specimens); GIPPSLAND LIMESTONE: PL3251, Merrimans Creek quarry (5 specimens); MANNUM FORMATION: PL3183, quarry, Bakers Hut Rd (14 specimens); PL3184, quarry at Taworri (32 specimens); PL3186, quarry at Kia Marina (24 specimens); PL3187, quarry at Younghusband (32 specimens); PL3191, cutting, Klose Rd, 6 km NE of Mannum (9 specimens); PL3192, Punthari cutting (2 specimens); PL3193, road cutting, Wongulla (12 specimens); PL3196, Big Bend Reserve (49 specimens); PL3212, Murray cliffs, 'Cave Cliff' (30 specimens); Mannum (3 specimens); lower beds, Murray cliffs, Overland Corner (3 specimens); lower beds, Murray cliffs opposite entrance to lagoon, Punyelroo (2 specimens); lower beds, Murray cliffs at Wongulla (8 specimens); lower beds, Murray cliffs from Wongulla to Mannum (7 specimens); AMS F5892, Swan Reach, Parish of Nildottie, SA (1 specimen); MELTON LIMESTONE: PL3295, Myponie Point (1 specimen); PL3296, Black Rock (1 specimen); NARACOORTE LIMESTONE: PL3247, James Quarry (1 specimen); ABRAKURRIE LIMESTONE: WAM 78.3949, Roaches Rest Cave, Madura district (1 specimen); POINT ADDIS LIMESTONE: Aireys Inlet (1 specimen); PUEBLA FORMATION: mouth of Jan Juc Creek, Torquay (2 specimens); yellow polyzoal limestone, beach N of Bird Rock, Torquay (5 specimens); ZEALLY LIMESTONE: Jan Juc Point, mouth of Spring Creek (2 specimens). **Batesfordian:** FYANSFORD FORMATION: PL3041, amphitheatre, Yarrowee River (2 specimens). **Balcombian:** railway cutting, South Yarra (3 specimens); MUDDY CREEK FORMATION: PL3082, Clifton Bank, Muddy Creek (1 specimen). **Bairnsdalian:** FYANSFORD FORMATION: PL3101, North Shore, Corio Bay (8 specimens).

Occurrence and time range. Aldingan to Bairnsdalian; although there are few Balcombian and Bairnsdalian records and, as noted above, Late Eocene–Early Oligocene specimens from the St Vincent Basin possibly represent an unnamed, ancestral species. Common at Janjukian and Longfordian localities in the Otway, Murray and St Vincent basins; one valve seen from the Longfordian Abrakurrie Limestone in the Eucla Basin. It is abundant in pure limestone lithologies, and uncommon to rare in terrigenous ones. It is very much the most abundant pectinid at many Mannum Formation localities along the Murray River, but is absent from the overlying Morgan Limestone (in which the only pectinid with a smooth exterior is *Amusium morganense* sp. nov.).

Remarks. *Victoripecten victoriensis* is very easily identified among Australian fossil scallops, because it is the only species with an almost circular, completely smooth (to the naked eye), polished exterior, and no internal rib carinae. Confusion with *Amusium* when the interior is not visible is much less of a problem than might be expected, as the two genera occur together only in Jan Juc Formation at Bird Rock cliffs, Torquay, Victoria (type Janjukian) and in Mannum Formation (Longfordian) on the Murray River, South Australia, and the species of *Amusium* occurring in both these formations is *A. subcostatum* sp. nov., with very weak radial costae on the exterior. Most specimens of *V. victoriensis* have 4–6 low but obvious radial costae on the proximal area of the RV auricle, fading out over the distal area; such RV auricle radials are present on a few specimens of the Miocene 'aff. *Lentipecten*' in New Zealand, but are not present on most specimens. The holotype of *V. victoriensis* also has 5 weak, obscurely defined radial costae on the distal part of the RV posterior auricle, but these are not present on many other specimens. The overall shape of the auricles is also quite variable; they have strongly convex anterior and posterior margins on the holotype and many other specimens, but on other (mostly smaller)

Fig. 42. *Victoripecten victoriensis* (Crespin), type species of *Victoripecten* gen. nov. A–C, E, holotype of *Lentipecten victoriensis* Crespin, AGSO CPC F16098, Lakes Entrance Formation (Janjukian), 300 m in Lakes Entrance Oil Shaft, Gippsland, Victoria: A, C, LV; B, E, RV; whole specimen at natural size, and auricles enlarged, × 3. D, P300234, RV, Tortachilla Limestone (Aldingan), Aldinga Bay, near Adelaide, South Australia; specimen with functional ctenolium, enlarged, × 1.25.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specimens they have much straighter margins and a more nearly square appearance. The raised, strongly convex dorsal auricular margin on the RV, strongly serrated by growth ridges, also adds to the rounded appearance of RV auricles, but of course LVs have straight dorsal margins, as in all other pectinids. The superficially similar RV of *Serripecten semilaevis* reaches a larger size than that of *V. victoriensis*, and also differs in its much wider umbonal angle, in its more inflated disc, in its much lower and wider, much more strongly serrated auricles, in lacking the obvious gill-suspensor muscle scars, and in its deeper byssal notch. Of course, this smooth valve is also always associated with the finely and evenly scaly LV of *Serripecten*. *S. semilaevis* also occurs in younger rocks than *V. victoriensis* (most records are Bairnsdalian).

Eocene and Early Oligocene records of *Victoripecten* are few, and their status is unclear. A total of only about 15 specimens has been seen (Fig. 42D) that are older than Janjukian, from Tortachilla Limestone and Port Willunga Formation in the St Vincent Basin. They are all markedly smaller than Janjukian–Longfordian adults (to *c.* 45 mm high), and a few RVs are well enough preserved to demonstrate that they retain a functional ctenolium at this height (Fig. 42B, D). However, adult RVs of *V. victoriensis* from Janjukian–Longfordian rocks also retain a functional ctenolium until about this height, although it appears to have been lost before adulthood by all Janjukian–Longfordian specimens. In view of the few specimens seen, it is unclear at present whether these pre-Janjukian specimens represent an unnamed, smaller, ancestral species, or are simply immature. At present we see no justification for recognising more than the one species, *V. victoriensis*.

Tribe Mimachlamydini Waller, 1993

Remarks. A diagnosis is provided above, under 'Classification'. Mimachlamydini differ from Chlamydini mainly in having a fixed number of undivided radial ribs, and in most members having carinae on the internal expression of the radial ribs, although some southern Australian species, such as *M. asperrima* (type species of *Mimachlamys* Iredale, 1929) and *M. heterophyseta* sp. nov., virtually lack the carinae (but note that a few thick-shelled individuals of *M. heterophyseta* sp. nov. examined have prominent carinae near the disc margins). Waller (1991; 1993: 228) regarded the pitted LV preradial microsculpture as an important character of the tribe, but the Australian fossil ancestors of *M. asperrima* have LV preradial microsculpture of intersecting commarginal and antimarginal ridgelets; it appears that the weakening of these ridgelets with time has produced the shallow pits of *M. asperrima*, as the Australian fossil record makes it quite clear that the Miocene species *M. sturtiana* (Tate) was the immediate ancestor of *M. asperrima*.

Waller (1993) discussed the characters and content of Tribe Mimachlamydini, including in it *Dimarzipecten* Ward, 1992, the new genus *Spathochlamys* Waller, 1993, and an unnamed genus for the Puerto Rican Oligocene, *Pecten sansebastianus* Maury, 1920. These are the only genera so far referred to the tribe. However, Dr Waller has pointed out to us (1999, pers. comm.) that many European Eocene–Oligocene fossil species have undivided primary costae and a herringbone interstitial microsculpture, and are similar to the living Mediterranean–Atlantic species *Mimachlamys varia* (Linné). They belong in either *Mimachlamys* or a closely related genus. One Late Eocene species reported here likely belongs in *Mimachlamys*, and it appears that this was a widespread genus by Middle to Late Eocene time.

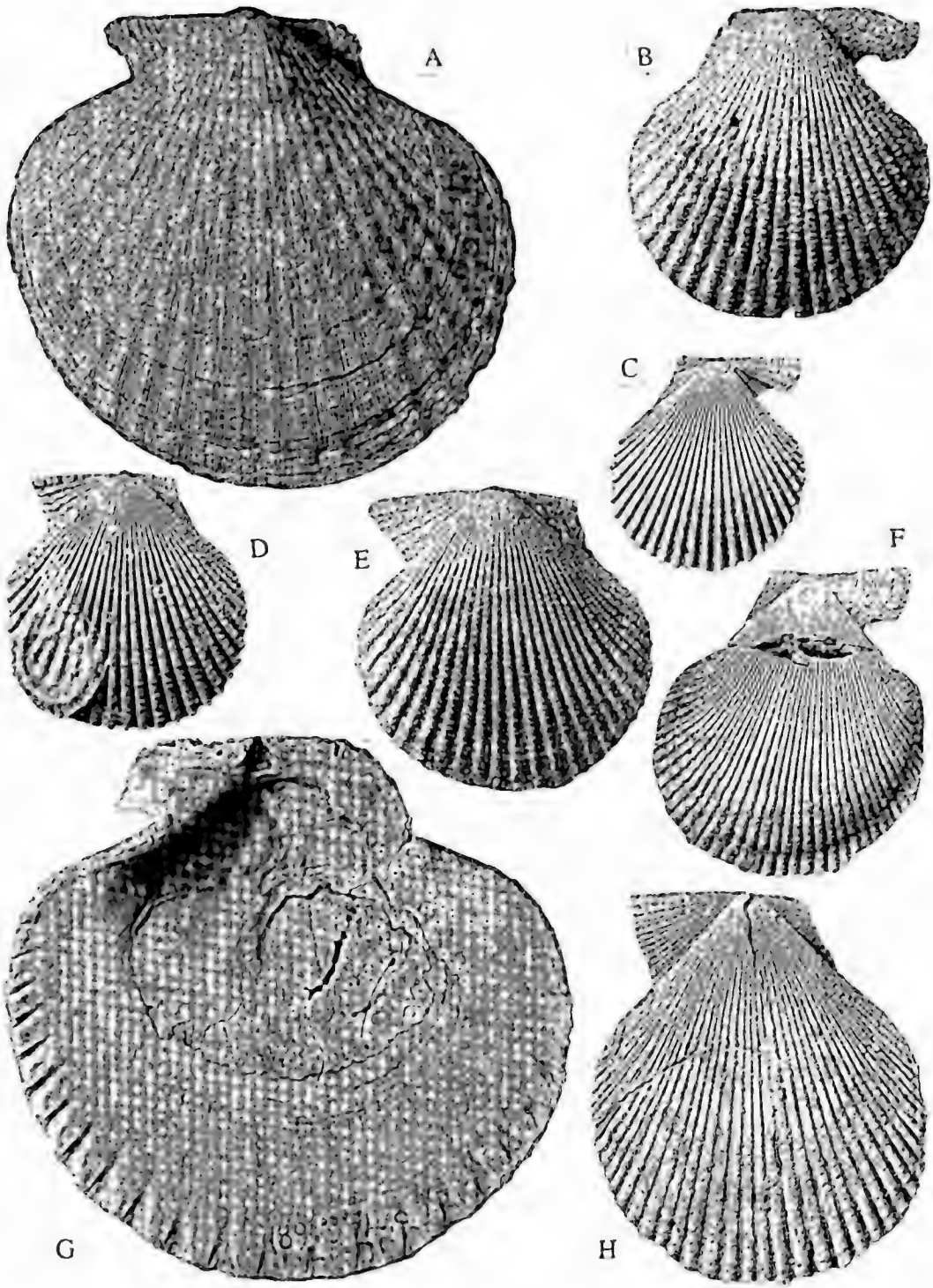
Genus *Mimachlamys* Iredale, 1929

Mimachlamys Iredale, 1929a: 162.

Type species (by original designation, Iredale 1929a: 188). *Pecten asperrimus* Lamarck, 1819, Late Miocene to Recent, southern Australia.

Remarks. The characters of the genus *Mimachlamys* are essentially those of the tribe. The scales on the costae and costellae of *Mimachlamys* are both cupped and directed ventrally, whereas in *Spathochlamys* Waller, 1993 (Late Miocene to Recent, eastern and western Central America) the scales are dorsally cupped, and the sculpture consistently includes a prominent median costella

Fig. 43. *Victoripecten victoriensis* (Crespin). A, C, E, F, Waurn Ponds Limestone (Janjukian), Blue Circle Southern Quarry, Waurn Ponds, near Geelong, Victoria; all at natural size: A, C, P302196, exterior and interior of LV; E, F, P302195, interior and exterior of RV. B, D, P300236, Port Willunga Formation (Aldingan), lower 3 m of cliff S of old jetty at Port Willunga, South Australia; SEMs of functional ctenolium of small specimen, H 33.4 mm, viewed from anterior end of anterior auricle: B, × 16 (field of view *c.* 4.5 mm wide); D, × 33.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filling each radial interspace. *Dimarzipecten* Ward, 1992, occurring in the Oligocene and Miocene of the eastern USA and of Caribbean islands, has ventrally cupped scales but no median costella and no internal rib carinae.

These, then, are the most primitive of the 'advanced' pectinids, differing from Chlamydini in their fixed rib number and in the presence of internal rib carinae in most species. All 'higher' pectinids (Australian members included below in tribes Decatopectinini, Palliolini and Pectinini) share these characters of a fixed number of radial costae and the presence of internal rib carinae. In Mimachlamydini, however, these advanced characters are shared with the more primitive characters of a chlamydoid shape, a primitive hinge type dominated by dorsal and resilial teeth, and a simple, pitted LV preradial sculpture (at least, in *M. asperrima*).

Mimachlamys? sp. nov.

Fig. 44F, H

Pecten flindersi Tate, 1886: 108 (in part, unfigured syntypes from 'Adelaide bore').

Remarks. Tate's (1886: 108) unfigured syntypes of *Pecten flindersi* from 'glauconitic sands, Adelaide bore' (ie., Kent Town bore) are weakly inflated, tall, narrow specimens (umbonal angle 90°) with an almost fixed number of radial costae (a small number of new costae is intercalated between the narrow costae near the anterior and posterior ends of the disc), with an unusual tall LV anterior auricle with an evenly convex, anteriorly sloping anterior margin, with fine, even antimarginal ridgelets across all radial interspaces, and with 40–45 low, wide, almost smooth, weakly convex-topped radial costae with very clearly defined edges. These specimens represent a pectinid we have not otherwise seen during this study, and appear likely to represent an unnamed species of *Mimachlamys*. As the species is known only by this small sample of six specimens, and the interiors are not visible, it is desirable to await better material before it is named.

Dimensions. SAM T943A H 23.6 L 21.0 RV
SAM T943F 29.9 23.1 LV

Material examined. SAM T943A–F, Tate's (1886: 108) unfigured syntypes of *Pecten flindersi*, from 'glauconitic sands, Adelaide bore', ie., Kent Town bore, South Australia, Aldingan.

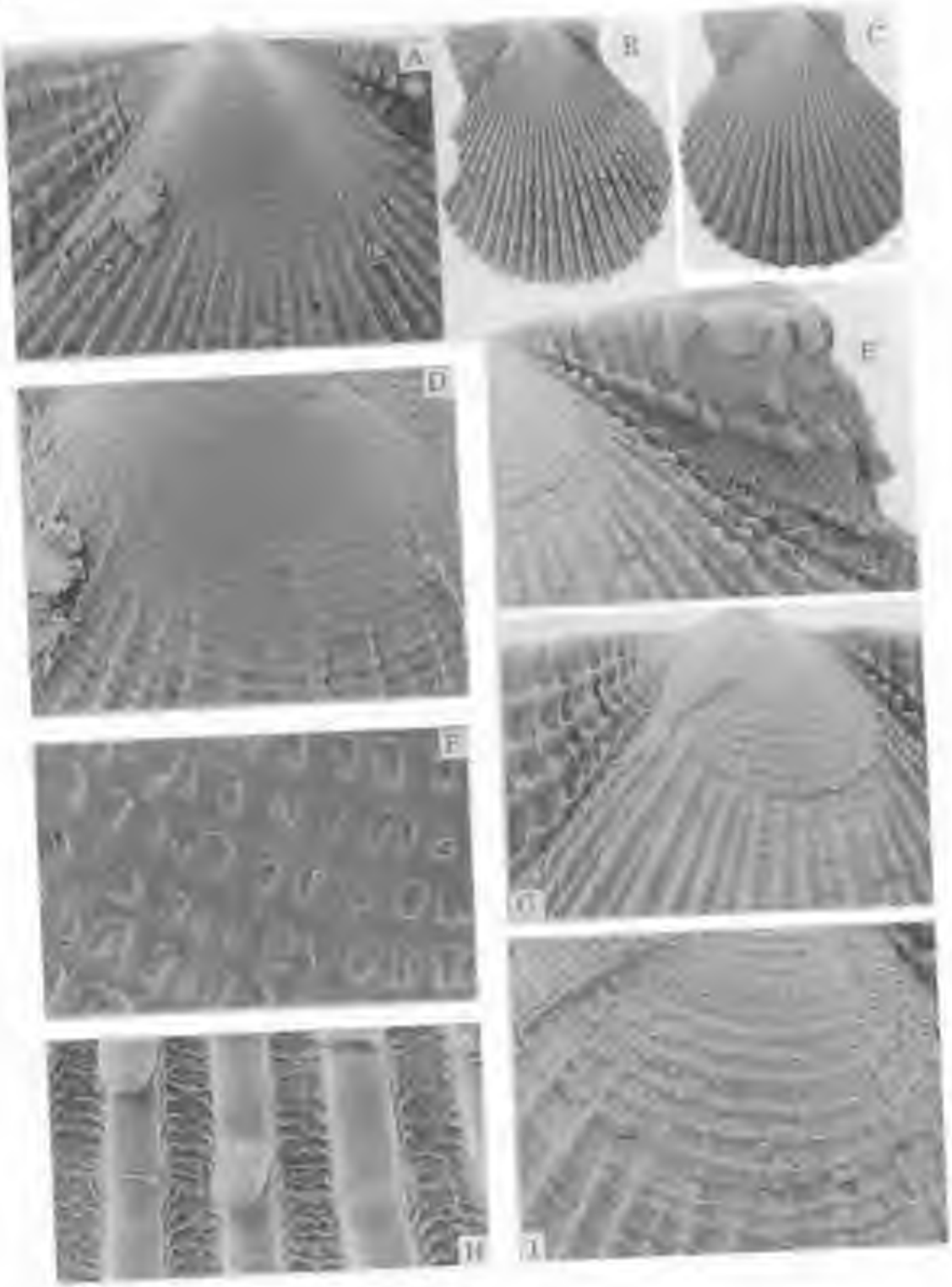
Mimachlamys sturtiana (Tate, 1886)

Figs 44B–E, 45A–I

Pecten sturtianus Tate, 1886: 109, pl. 7, fig. 2a–c; Tate & Dennant, 1893: 24; Harris, 1897: 315; Tate, 1899: 270.

Description. Small (rarely exceeding 20 mm high), moderately well inflated, the two valves equally inflated; acline to weakly prosocline; umbonal angle low (*c.* 95°) in juveniles, which are tall and narrow, increasing to *c.* 110° in adults, which are markedly wider, with length about equal to height. Exterior sculpture of 24–28 simple, well raised, moderately wide radial costae with weakly convex crests, each interspace about equal to or slightly narrower than one costa, fixed in number throughout ontogeny and without secondary or finer sculpture in most specimens; fine, scaly secondary costellae subdividing from costal edges over distal quarter (or less) of disc on some specimens, particularly Balcombian–Bairnsdalian ones; costal crests bearing low, moderately wide, flat to weakly ventrally cupped, ventrally inclined scales, numerous and closely spaced all over most well preserved specimens but easily abraded. Radial interspaces crossed by low commarginal lamellae immediately after costal inception, but lamellae quickly lost, afterwards combining with antimarginal ridgelets to produce complex wavy ridgelets that fill interspaces over most of shell. RV anterior auricle very long and narrow, extending to anterior margin of disc

Fig. 44. A, G, *Mimachlamys heterophyseta* sp. nov., Middle Pleistocene (Oxygen Isotope Stage 7), sewerage excavation, Catholic School, Busselton, southern Western Australia: A, very large LV, WAM 89.974a, reduced to ×0.67; G, interior of unusually thick RV, WAM 89.974c, showing internal rib carinae around ventral margin; at natural size. B–E, *Mimachlamys sturtiana* (Tate), four of Tate's (1886) 11 syntypes: B, figured paralectotype RV, SAM T935B, and E, figured syntype LV (here designated lectotype of *Pecten sturtianus* Tate), SAM T935A, 'Eocene, Murray cliffs', ie., Morgan Limestone (Balcombian), River Murray, South Australia; C, D, SAM T935K, T935J, unfigured paralectotypes, RV (C) and LV (D), 'Muddy Creek' (Balcombian), near Hamilton, western Victoria; all enlarged, ×2.5. F, H, *Mimachlamys* sp. nov., 2 (of 6) unfigured paralectotypes of *Pecten flindersi* Tate, 'Adelaide Bore', ie., Kent Town bore, Aldingan; both enlarged, ×2: F, RV, SAM T943A; H, LV, SAM T943F.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on many specimens, with wide, deep byssal notch and functional ctenolium in all specimens; LV anterior auricle long, tall, with weakly concave to weakly convex anterior margin, sloping strongly towards anterior; posterior auricles small, narrow but tall, with weakly concave posterior outline, sloping strongly towards anterior; anterior auricles sculptured as on disc; posterior auricles weakly sculptured, with prominent, nodulose or scaly dorsal ridge but only 1–3 very narrow radial costae lower down. Interior strongly corrugate in small (thin) specimens, more weakly so in larger, thicker ones, with prominently notched (crenulate) ventral margin showing weak signs of carinae on some specimens. Hinge with narrow to quite wide, prominent dorsal and resilial teeth in RV and corresponding sockets and infradorsal ridge in LV.

Dimensions.

Lectotype of *Pecten sturtianus* SAM T935A	H	18.5	L 18.1	LV
Paralectotype, SAM T935B		19.0	18.6	RV
Paralectotype, SAM T935J		15.6	14.8	LV
Paralectotype, SAM T935K		12.6	11.8	RV
NMV P302147, Blanchetown cutting		20.5	18.8	LV

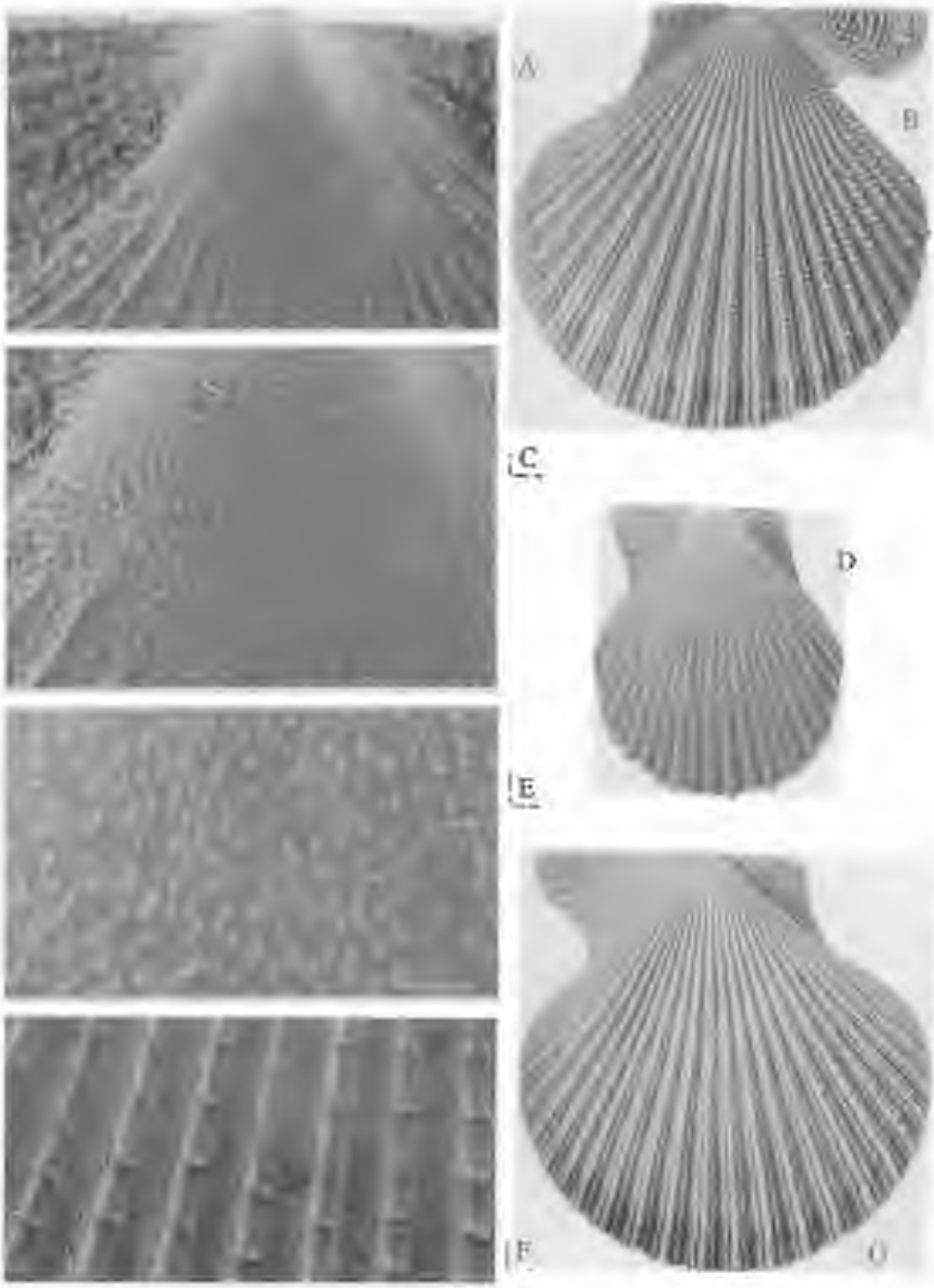
Type material. *Pecten sturtianus* Tate, 1886, lectotype designated here, SAM T935A, Tate's (1886: pl. 7, fig. 2a) figured syntype LV, and 10 paralectotypes, SAM T935B–G labelled 'Eocene, Murray cliffs' and SAM T935H–K labelled 'Muddy Creek'; ie., the lectotype and specimens T935B–G are from Morgan Limestone (Balcombian), River Murray cliffs, and specimens T935H–K are from Muddy Creek Formation (Balcombian), Muddy Creek.

Other material examined. **Janjukian:** JAN JUC FORMATION: PL3025, Fishermans steps, Torquay (3 specimens). **Longfordian:** MANNUM FORMATION: PL3188, Mannum pumping station (2 specimens); PL3190, cutting, Underwood Hill Rd (3 specimens); PL3218, Murray cliffs, 'Yarra Glen' (1 specimen); PL3196, Big Bend Reserve (1 specimen); lower bed, River Murray cliffs from Wongulla to Mannum (1 specimen); WAM 90.98, cliffs E side Murray River, E side of Ponde Rd, immediately E of Mannum (1 specimen); WAM 94.363, Mannum (1 specimen); PORT WILLUNGA FORMATION: PL3597, Angle Vale bore (4 specimens). **Balcombian:** CADELL MARL: PL3084, Cadell Marl lens (16 specimens); FYANSFORD FORMATION: PL3070, Farrels (1 specimen); PL3072, Ad28, Orphanage Hill, Fyansford (5 specimens); PL3074, caisson shaft, Dingley (7 specimens); PL3077, Altona Bay coal shaft (20 specimens); PL3078, Fossil Beach, Mornington (43 specimens); MORGAN LIMESTONE: PL3189, Mannum pumping station road cutting (1 specimen); PL3197, Greenways Landing (7 specimens); PL3198, Blanchetown Bridge cutting (36 specimens); PL3200, S of Moorundie (5 specimens); PL3202, Adams St, Blanchetown (1 specimen); PL3203, South Australian Water Ski Assoc. (5 specimens); PL3205, Woods Flat Post Office (5 specimens); PL3206, Bryants Creek Reserve (5 specimens); PL3208, Murray cliffs, Great Yarra Reach (14 specimens); PL3211, Murray cliffs, 'Karelia' (1 specimen); PL3215, Murray cliffs, 'Nikalepko' (2 specimens); PL3217, Murray cliffs, 'Yarra View' (8 specimens); River Murray cliffs at Morgan (16 specimens); 6.4 km below Morgan (1 specimen); Tate's bed 9, 6.4 km below Morgan (1 specimen); WAM 93.485, Blanchetown (2 specimens); AMS, River Murray cliffs (6 specimens); MUDDY CREEK FORMATION: PL3082, Clifton Bank, Muddy Creek (97 specimens); lower beds, Muddy Creek (25 specimens); WAM and AMS, Muddy Creek, Hamilton (72 specimens). **Bairnsdalian:** FYANSFORD FORMATION: PL3099, junction Barwon River and Native Hut Creek, Inverleigh (2 specimens); PL3100, Murgheboluc 4A (1 specimen); middle beds, Grices Creek (2 specimens); AMS, PL3104, cliff S of Manyung Rocks (1 specimen); RUTLEDGE CREEK MEMBER, PORT CAMPBELL LIMESTONE: PL3093, Rutledge Creek (1 specimen); PATA LIMESTONE: PL3213, Ramco Point (7 Specimens).

Occurrence and time range. Janjukian to Bairnsdalian; not common in Bairnsdalian rocks. Examination of a larger range of well preserved early material is desirable to clarify the early history of the *M. sturtiana* species group. The only Australian Eocene record of *Mimachlamys* is the unnamed species discussed above. Specimens assigned to *M. sturtiana* occur in Janjukian rocks at Torquay, Victoria, are uncommon in Port Willunga Formation in St Vincent Basin, are common in Mannum Formation and Morgan Limestone in the Murray Basin, and are moderately common at Muddy Creek in the Otway basin. The only Bairnsdalian specimens we have seen are from Fyansford Formation around Melbourne.

Remarks. *Mimachlamys sturtiana* is easily distinguished from *M. asperrima* by its much smaller size, its greater inflation, its virtually complete

Fig. 45. *Mimachlamys sturtiana* (Tate), SEMs of small LVs. A, B, D, F, H, P300279, Fyansford Formation (Balcombian), Altona Bay coal shaft, Victoria: B, whole shell enlarged, × 7.6 (H 5.5 mm); enlargements of sculpture of preradial dissoconch (A × 33, D × 65, F × 260) and of sculpture near ventral margin of disc (H × 60), showing simple, weakly concave scales characteristic of this species. C, E, G, I, P300269, Port Willunga Formation (here Longfordian), bore 17-2, 'Sylvan Glades', Angle Vale, South Australia: C, whole shell enlarged, × 4 (H 10.3 mm); enlargements of posterior auricle (E × 25) showing few radial costae, and of sculpture of preradial dissoconch (G × 25, I × 50), clearly more coarsely sculptured than in the younger specimen (Fig. 45A, D, F).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lack of subdivision of the primary radial costae into secondary or finer costellae, its more weakly sculptured posterior auricles, and its more prominent LV preradial dissoconch sculpture than in *M. asperrima*. The LV preradial sculpture (Fig. 45A, D, F) consists of obvious commarginal ridges and antimarginal ridgelets, all of even height, so when they are a little abraded they form sculpture similar to the very shallow pits in an otherwise smooth surface of *M. asperrima* (Fig. 46A, C, E), but the pits are larger, deeper and more nearly rectangular than in *M. asperrima*; in the protected hollows between the umbonal area and the auricles, the pits clearly are surrounded by low ridges. Although there are no true internal rib carinae, the interior of the ventral margin is strongly notched in conformity with the external costae, a condition which appears to be the precursor of carinae forming further up the shell. The apparently rapid, but far from geologically instantaneous, evolution of *M. asperrima* from *M. sturtiana* during Bairnsdalian time is described under *M. asperrima*.

Four small *Mimachlamys* specimens from Port Willunga Formation (here Longfordian; Lindsay 1969; bore 24) in PL3597, bore on 'Sylvan Glades', Angle Vale, South Australia (NMV P300269, P300271, P300426–7) agree with *M. sturtiana* in every detail of size, shape and dissoconch sculpture, but the LV preradial dissoconch (Fig. 45C, G, I) has considerably coarser commarginal ridges and antimarginal ridgelets than in the Balcombian specimens studied by SEM (Fig. 45A, D, F; from Fyansford Formation at Balcombe Bay). It seems likely that further study of early specimens of small *Mimachlamys*, of Janjukian to Longfordian and perhaps Batesfordian age, would demonstrate that this coarser LV preradial sculpture is consistent, and they could be separated as a distinct species. However, most of the early material we have available is from limestone, and has abraded LV preradial dissoconch areas. We are, therefore, unable to demonstrate that LV preradial dissoconch sculpture does not simply decrease gradually in prominence with time, and we retain all Bairnsdalian and older small *Mimachlamys* material in the single species *M. sturtiana* (other than Tate's Eocene material from the Kent Town bore).

Mimachlamys asperrima (Lamarck, 1819)

Figs 46A–G, 47A–D, F, 52C

Pecten asperrimus Lamarck, 1819: 174; Deshayes, 1836: 145; Delessert, 1841, pl. 15, fig. 1a, b; Sowerby, 1842: 75, pl. 17, fig. 156; Chenu, 1844: pl. 33, figs 4–6; Menke, 1844: 90; Reeve, 1853: pl. 20, fig. 75; Angas, 1877: 193; Tenison Woods, 1878: 56; Smith, 1885: 294; Tate, 1887c: 108; Harris, 1897: 315; Hedley, 1916a: 8; Odhner, 1917: 14; Thiele, 1930: 591; Dijkstra, 1995: 485, pl. 24, figs 101–104.

Ostrea matonii Donovan, 1824, vol. 3, conchology pl. 91.

Pecten australis Sowerby, 1842: 76, pl. 19, figs 219, 220; Reeve, 1853: pl. 25, fig. 103a, b.

Pecten rubidus 'Martyn'; Menke, 1843: 36.

Pecten asperrimus var.; Tate, 1882: 34.

Pecten antiaustralis Tate, 1886: 106, pl. 9, fig. 7a–c; Harris, 1897: 315; Tate, 1899: 269.

Pecten asperrinus [*sic*]; Tate & May, 1901: 440.

Chlamys asperrimus [*sic*]; Hedley, 1902: 307; Pritchard & Gatliff, 1904: 264; Hedley, 1918: M9; May, 1921: 10; May, 1923: pl. 3, fig. 7; Macpherson & Gabriel, 1962: 303, fig. 344; Macpherson, 1966: 232; Wells & Bryce, 1985: 158, fig. 581.

Mimachlamys asperrimus [*sic*]; Iredale, 1929a: 162; Allan, 1950: 280, pl. 37, fig. 3; Cotton, 1961: 105, fig. 90.

Chlamys asperrimus asperrimus [*sic*]; Gatliff & Singleton, 1930: 73, pl. 2, figs 1, 2, 4; pl. 3, fig. 5; pl. 4, figs 11a, b, 12.

Chlamys asperrimus antiaustralis; Gatliff & Singleton, 1930: 71, pl. 2, fig. 3; pl. 3, figs 6, 7; pl. 4, fig. 10a, b.

Chlamys asperrimus dennanti Gatliff & Singleton, 1930: 73, pl. 3, figs 8, 9; pl. 4, fig. 13a, b.

Mimachlamys antiaustralis; Cotton, 1947: 655 (list).

Chlamys (Chlamys) antiaustralis; Ludbrook, 1955: 30, pl. 5, fig. 11; Ludbrook, 1959: 223.

Mimachlamys asperrima; Garrard, 1961: 5; Waller, 1991: 32, pl. 4, figs 4, 5; Lamprell & Whitehead, 1992: pl. 9, fig. 50.

Chlamys (Chlamys) asperrimus asperrimus [*sic*]; Ludbrook, 1983: 39.

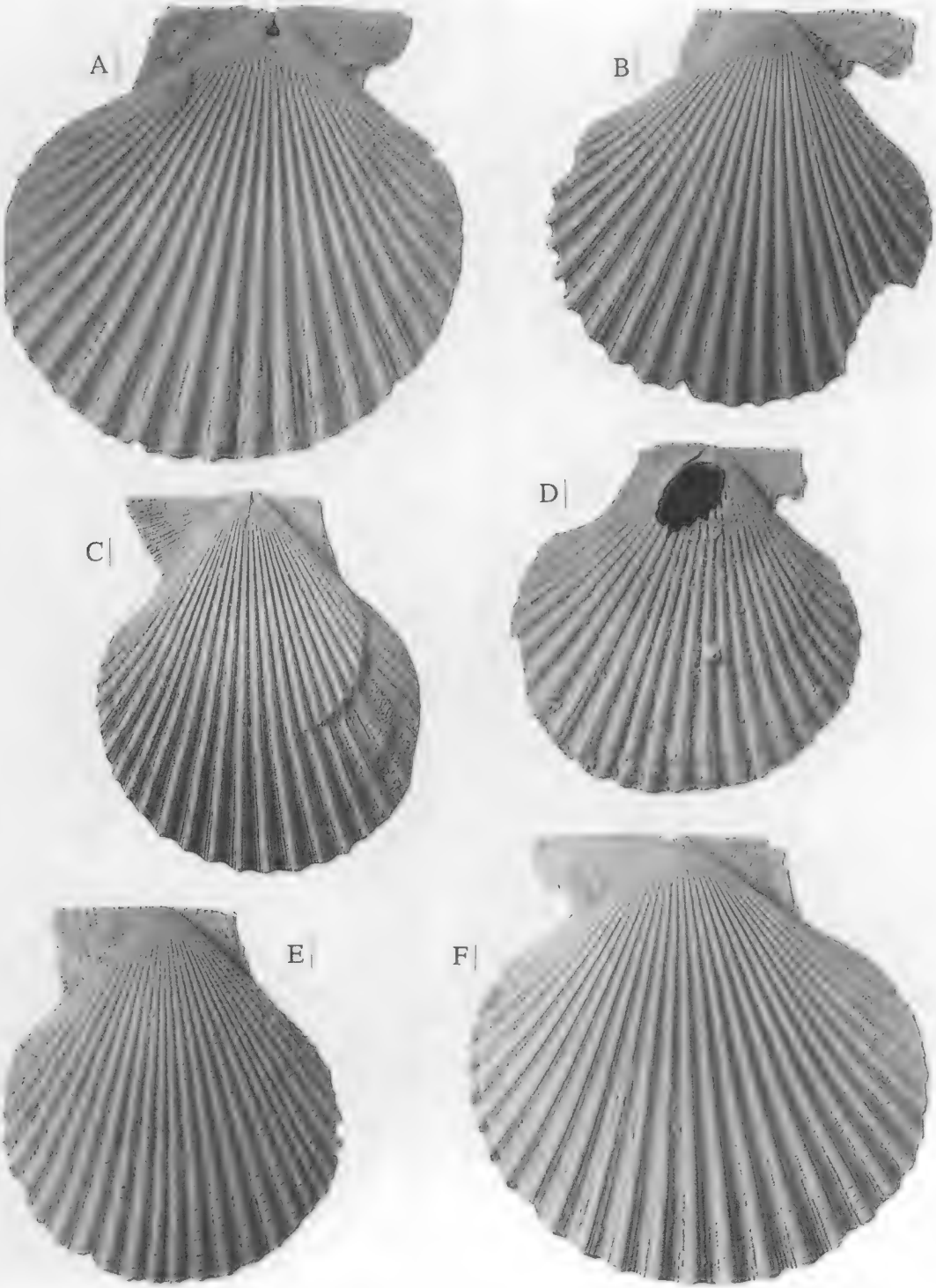
Chlamys (Chlamys) asperrimus [*sic*] *dennanti*; Ludbrook, 1983: 39.

Chlamys (Chlamys) asperrima; Ludbrook, 1984: 160, 238, fig. 41a, pl. 4f–i.

Chlamys (Chlamys) asperrima dennanti; Ludbrook, 1984: 238.

Chlamys (Mimachlamys) asperrima; Rombouts, 1991: 27, pl. 10, fig. 3a, b.

Fig. 46. Mimachlamys asperrima (Lamarck), type species of *Mimachlamys* Iredale, 1929. A, C–F, SEMs of small LV, AMS C300338, Recent, 7.5 m, near jetty, Killora Bay, D'Entrecasteaux Channel, SE Tasmania: D, whole shell, × 7.6 (H 6 mm); enlargements of sculpture of preradial dissoconch (A × 33, C × 70, E × 140) and of sculpture near ventral margin of disc (F × 38). B, G, moderately large, coarsely sculptured Recent specimen with large anterior auricles, WAM 21.57, piles of naval jetty, Woodman Point, near Fremantle, Western Australia, at natural size: B, RV; G, LV.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Description. Moderately large (to *c*. 100 mm high), markedly taller than wide when young, length about equal to height in adults; moderately to quite strongly inflated, the two valves equally inflated; umbonal angle *c*. 95° in juvenile specimens, increasing to *c*. 110° in adults; most specimens weakly prosocline, some juvenile specimens acline; retaining very long, narrow RV anterior auricle and byssally attached habit in largest adults. Exterior sculpture of 24–30 prominent radial costae, fixed in number and undivided throughout ontogeny; from a disc height of *c*. 15–20 mm low, narrow secondary costellae subdivide from edges of primary costae and, on most large specimens, very low, narrow, tertiary and still finer costellae develop in radial interspaces over distal quarter, or less, of disc; costae therefore arranged in fasciculate groups evenly over both valves; costal crests bearing low, wide to quite prominent, ventrally directed scales, prominent in radial interspaces (ie., on costellae) in almost all specimens but abraded off primary costae of most specimens. Floors of radial interspaces bearing complex microsculpture of intersecting commarginal and antimarginal ridgelets, producing a herringbone pattern over much of shell. RV anterior auricle large, elongate, with deep byssal notch; LV anterior auricle long, with deeply sinuous anterior margin, sloping strongly towards anterior; posterior auricles moderately large, tall, with straight posterior margin sloping moderately strongly towards anterior. Interior strongly corrugate, with weak rib carinae developed on edges of corrugations around inside of ventral margin on some specimens. Hinge dominated by prominent, thick, widely diverging resilial teeth in RV and corresponding hollows alongside resilifer in LV, dorsal teeth prominent but less so than resilial teeth.

Dimensions.

Lectotype of *P. asperrimus* (Dijkstra, 1995: 488)	H 98.0	L 88.5	2 valves
Lectotype of *P. antiaustralis* Tate	68.1	68.7	2 valves
Holotype, *C. asperrimus dennanti* Gatliff & Singleton	H 58.7	L 53.2	RV
Paratype, *C. asperrimus dennanti* NMV P13504	56.9	48.1	LV

Type material. Lectotype of *Pecten asperrimus* Lamarck, 1819, designated by Dijkstra (1995: 488), MNHN (Dijkstra 1995: pl. 24, figs 101–104), from 'les mers australes, à la Nouvelle Hollande, les côtes de Diémen, Péron et Le Sueur', indicating that it was collected in Australia (including Tasmania) by Péron and Lesueur during the voyage of the '*Géographe*' and the '*Naturaliste*'; with 4 paralectotypes in MNHN and 7 in MHNG. Donovan's (1824 [in 1823–1834]: vol. 3, conchology pl. 91) illustration of *Ostrea matonii* is a beautiful, delicate, accurate watercolor of *Mimachlamys asperrima*; the repository of any original material from this work is not known. Donovan (1824) gave the locality as 'Van Diemen's Land', ie., Tasmania. The lectotype of *Pecten asperrimus* Lamarck, 1819 is here designated the neotype of *Ostrea matonii* Donovan, 1824. *Pecten australis* G. B. Sowerby II, 1842, 3 'probable' syntypes in BMNH (H. H. Dijkstra, August 1998, pers. comm.), not seen. Lectotype of *Pecten antiaustralis* Tate, 1886, designated here, Tate's (1886: pl. 9, fig. 7a–c) figured syntype, SAM T.928A, from 'oyster beds, Aldinga Bay', ie., Hallett Cove Sandstone, Late Pliocene, near Adelaide. Holotype of *Chlamys asperrimus dennanti* Gatliff & Singleton, 1930, NMV P13503, from Werrikoo Limestone, above Limestone Creek, Glenelg River, western Victoria, ex J. Dennant coll.; paratype, NMV P13504, all data as holotype. We have not seen the type material of the other nominal taxa listed in the synonymy.

Other material examined. **Bairnsdalian:** BAIRNSDALE LIMESTONE: foot of walking track, Myrtle Point, allot. 4, section B, Parish of Wy Yung, Bairnsdale (1 specimen); FYANSFORD FORMATION: Grices Creek (1 specimen); sewer excavation, Powell St nr Davis St, South Yarra (1 specimen). ?MUDDY CREEK FORMATION (age and stratigraphy uncertain): blue beds at Clifton Bank, Muddy Creek (1 specimen). **Mitchellian:** TAMBO RIVER FORMATION: PL3110, Swan Reach cutting (491 specimens); PL3259, Burnt Bridge (3 specimens); PL3260, S of Burnt Bridge (7 specimens); PL3261, Long Point (4 specimens); PL3262, SE of Long Point (1 specimen); PL3266, E of Long Point (9 specimens); PL3267, Reedy Arm peninsula, Lake Tyers (2 specimens); PL3269, Trident Arm (32 specimens); Latham's cliff, Tambo River, NE

Fig. 47. A–D, F, *Mimachlamys asperrima* (Lamarck): A, F, lectotype (designated here) of *Pecten antiaustralis* Tate, SAM T928A, 'oyster bed, Aldinga Bay', ie., Hallett Cove Sandstone (Late Pliocene), coast near Adelaide, South Australia; RV (A) and LV (F), at natural size; B, P301147, RV, early form with few scales and with secondary costae only just beginning to subdivide from primary costae, Fyansford Formation (Bairnsdalian), Grice's Creek, Mount Eliza, Victoria, enlarged, × 2; C, paratype of *Chlamys asperrima dennanti* Gatliff & Singleton, 1930, LV, P13504, Werrikoo Limestone (Late Pliocene), Glenelg River, SE Victoria, at natural size; D, P301116, RV, Bairnsdale Limestone (Bairnsdalian), Myrtle Point, Mitchell River, Bairnsdale, Gippsland, Victoria, early form as in Fig. 46B, enlarged, × 1.5. E, *Mimachlamys funebris* (Reeve), WAM 79.2127, lower shellbed, Dampier Limestone (Late Pleistocene), Peron Peninsula, 3 km S of Broadhurst Bight, Shark Bay, Western Australia; a single LV, enlarged, × 1.25.

corner allot. 69A, Parish of Bumberrah (4 specimens). **Cheltenhamian:** GOODWOOD FORMATION: PL3132, Spring Creek, Minhamite (38 specimens); BLACK ROCK SANDSTONE: Windsor railway cutting (1 specimen); Beaumaris (4 specimens); JEMMYS POINT FORMATION: PL3115, Lake Bunga crossing (33 specimens); PL3116, old highway, Bunga Creek (18 specimens); PL3117, second lowest bed, Bunga Creek (63 specimens); PL3118, Mississippi Creek tramway cutting (68 specimens); PL3119, Ritchies Cutting (79 specimens); PL3127, Mississippi Creek tramway terminus (3 specimens); lower bed, Bunga Creek road cutting (11 specimens); top of Bed A, east cutting Bunga Creek (8 specimens); east cutting, Bunga Creek (40 specimens); lowest shell bed, east cutting, Bunga Creek (7 specimens); Mississippi Creek, Lakes Entrance (1 specimen); PL3123, Ferndale Parade, Lakes Entrance (8 specimens); PL3122, S of Hunter Gully (1 specimen); PL3124, N side Hunter Gully (8 specimens); PL3126, Nautilus Way (3 specimens); PL3270, Ironbark Track (4 specimens); PL3272, Trident Arm Track (1 specimen); MOORABOOL VIADUCT SANDS: PL3131, Moorabool Viaduct (6 specimens); Moorabool (2 specimens); nodule bed, cliff on left bank Moorabool River at old quarry, 100 m W of Shelford Cemetery (2 specimens); Shelford (17 specimens); Leigh River, Shelford (11 specimens). **Kalimnan:** GRANGE BURN FORMATION: PL3137, Forsyth's Bank, Grange Burn (31 specimens); PL3138, Grange Burn gorge (25 specimens); PL3139, McDonald's Bank, Muddy Creek (51 specimens); AMS, Muddy Creek (5 specimens); JEMMYS POINT FORMATION: PL3141, Bunga Creek west cutting (30 specimens); Princes Highway at Lake Bunga (5 specimens); cutting, Princes Highway, east bank Bunga Creek (4 specimens); PL3147, Nyerimalang Jetty (2 specimens); PL3148, Kalimna Jetty (42 specimens); PL3150, Hopkins Bight (1 specimen); PL3151, Nyerimalang Estates Rd (65 specimens); PL3274, W end Godsells Point (4 specimens); GSV F5, 5–7 m, North Arm Bridge road cutting, Kalimna (7 specimens); water level, right bank Toorloo Arm, 1 km N of Toorloo House, Lake Tyers (3 specimens); low cliff, S of allot. 30E, section A, Parish of Colquhoun (2 specimens); WAM 79.2371, lower beds, Meringa Creek, Lakes Entrance (10 specimens); Meringa Creek, Kalimna (29 specimens); Jemmys Point, Kalimna (25 specimens); Nyerimalang (7 specimens); lower shellbed, 4 m above Meringa Creek, E of bridge (16 specimens). **Late Pliocene:** ASCOT FORMATION: (undifferentiated, age uncertain) WAM 86.1241, spoil heap, Iley's bore, lot 141, corner Forrest and Warton roads, Banjup, WA (1 specimen); ('older' part) WAM 94.1014, 25.0–28.6 m, Larsen's bore, corner Gingin Brook and Telephone roads, West Gingin, WA (51 fragments); DRY CREEK SANDS (presumably from upper part): PL3299, Abattoirs Bore (41 specimens); PL3611, Royal Adelaide Golf Course bore (7 specimens); 131–134 m, Beach Petroleum Grange Oil Well (21 specimens); HALLETT COVE SANDSTONE: PL3291, Giles Point (13 specimens); PL3467, Port Willunga (4 specimens); PL3600, upper part of cliff, Blanche Point (3 specimens); Port Willunga (5 specimens); Aldinga (30 specimens); Edithburgh (2 specimens); WAM, Port Willunga (11 specimens); NORWEST BEND FORMATION: PL508, Jervois Punt (27 specimens); PL3179, Fred's Landing (139 specimens); PL3281, Lagoon Rd, Murray River (64 specimens); upper beds, Murray River, at Wongulla (8 specimens); 1.3 m sandstone at depth of 2.4 m below surface, Moorlands (2 specimens); Mannum Council rubbish pit, Mannum, South Australia (1 specimen); ROE CALCARENITE: PL3167, pit 1.6 km N of Hampton Tower (80 specimens); PL3172, Hampton Tower (7 specimens); pit 0.6 km N of PL3172 (5 specimens); pit on N side Eyre Highway, Eucla 446 482 (3 specimens); WERRIKOO LIMESTONE: PL3153, Minnie Creek (1 specimen); Limestone Creek (14 specimens); 10 m above Glenelg River at Roscoe's Cliff (4 specimens); WAM 88.462, float from base of cliff, Whalers Bluff, Victoria (1 specimen). **Early Pleistocene:** 'YOUNGER' ASCOT FORMATION, Perth Basin: WAM 65.368, 14.9 m, Gilbert's bore, Lot 192, West Coolup (1 specimen); WAM 67.568, 38.4–39.3 m, Adrian's Nursery bore, corner Thomas and Semple roads, Jandakot (6 specimens); WAM 67.796, 33.5 m in above bore (2 specimens); WAM 70.1039, 43.6 m, Schafer's bore, Beenyup Rd, Banjup (1 specimen); WAM 70.1435, 41.3–42.1 m, Poletti's No. 1 bore, W side Semple Rd, Jandakot (4 specimens); WAM 71.842, 31.7–37.2 m, Pedersen's bore, Russell Rd, Success (4 specimens); WAM 72.1922, 33.5–33.7 m, Jandakot Cement Works bore, Parkes Rd, Yangebup (2 specimens); WAM 72.2127, 33.5 m in above bore (1 specimen); WAM 74.236, 41.6–41.8 m, Paulik's bore, Semple Rd, Jandakot (10 specimens); WAM 75.649, spoil from seismic shotholes, near Greenlands Rd, 7 km WSW of Pinjarra (4 specimens); WAM 76.106, 38.9 m, Paulik's bore, Semple Rd, Jandakot (4 specimens); WAM 76.768, 37.5–37.6 m in above bore (3 specimens); WAM 76.986, 37.4 m in above bore (12 specimens); WAM 76.1269, 34.8 m in above bore (2 specimens); WAM 76.1442, 34.2–34.8 m in above bore (2 specimens); WAM 86.1327, 20 m, Interface No. 10 borehole, Sir James Mitchell Park, South Perth (1 specimen); MEMANA FORMATION: PL1202, 'Brunah' A (1 specimen); PL1205, 'Brunah' B (3 specimens); PL1207, 'Brunah' D (1 specimen); PL1217, 'Marapana' B (1 specimen). **Middle Pleistocene:** TAMALA LIMESTONE, PEPPERMINT GROVE MEMBER: WAM 65.1065, shellbed in cliff near Scotch College boatshed, Peppermint Grove, WA (1 specimen). (Other young fossils not listed.)

Occurrence and time range. As noted above, we know of only two or three specimens of *M. asperrima* from Bairnsdalian rocks; widespread and abundant throughout southern Australia in all Late Miocene to Pleistocene shallow-water lithologies, and living from south-central Western Australia around southern Australia to southern Queensland.

Remarks. Among the southern Australian fossil scallops reviewed here, *Mimachlamys asperrima* is exceeded in size only by *M. heterophyseta* sp. nov. and *M.* sp. nov. from Shark Bay. *M. sturtiana* reaches a height of about 20 mm, whereas *M. asperrima* is commonly 70 mm high and reaches 100 mm. The fixed number of primary costae, the weak internal rib carinae around the interior of the

ventral margin, the obvious, fine, scaly secondary and tertiary sculpture between the primary costae, the retention of the byssally attached habit in adult specimens, and the equally inflated valves are also important diagnostic characters. The form from 'Swan River', Western Australia, named *Pecten australis* by G. B. Sowerby II (1842: 76, pl. 19, figs 219, 220; illustrated more clearly by Reeve 1853: pl. 25, fig. 103a, b) falls within the variation of *M. asperrima*. Dr T. R. Waller (1998, pers. comm.) pointed out this synonymy.

Inflation is highly variable in *M. asperrima*. Although most specimens are only moderately inflated, a few specimens are seen in most large collections that are very strongly inflated (eg., AMS C147520, Sheepwash Bay, west coast of Bruny Island, Tasmania, 10–12 m; 5 large, inflated, articulated pairs, four of which are unusually strongly inflated, one of them extremely so). The point here, though, is that matching LVs and RVs are almost equally inflated in all examined specimens of *M. asperrima*. This provides the main distinguishing character from *M. heterophyseta*, which has strongly discrepant valve inflation.

Gatliff & Singleton (1930) examined the disc shape and sculpture of several young populations of *M. asperrima* in southern Australia. They maintained Tate's *Pecten antiaustralis* as a subspecies of *M. asperrima* for Pliocene fossils from near Adelaide, despite reporting that intermediate specimens occurred, and proposed another subspecies, *M. asperrima dennanti*, for unusually tall, narrow, coarsely sculptured specimens (Figs 47C, 52C) occurring in Werrikoo Limestone (probably latest Pliocene in age), Glenelg River, western Victoria. In our opinion, both 'subspecies' are simply part of the variation of *M. asperrima*. We have examined Tate's types of *P. antiaustralis* and a large range of Pliocene fossil material from both South Australia and Victoria, and can see no consistent differences whatever from *M. asperrima*. The minor range of variation in shape, inflation and sculpture shown by the Pliocene fossils is closely similar to that of the nearby living population.

The Werrikoo Limestone population warrants comment, however. The 19 specimens from Werrikoo Limestone in NMV are moderately variable in shape and sculpture, but on the whole the collection is remarkably consistent in the unusually tall, narrow shape and in the coarseness of sculpture of all specimens. Major costal crests are wide and almost smooth on most specimens, suggesting they have suffered abrasion, whereas (as was shown by Gatliff & Singleton 1930) interstitial costellae are unusually weak, developing relatively late in ontogeny, their interspaces are wide and almost smooth, and costellae bear unusually coarse, long scales. Examination of the extensive AMS collection of Recent material showed that specimens just as coarsely sculptured and specimens just as tall and narrow occur in the present-day population; eg., AMS C107275, dredged in 7.5 m, Killora Bay, D'Entrecasteaux Channel, SE Tasmania, includes one tall, narrow RV with wide, smooth, primary costal crests, a secondary costa on each side of each primary one bearing long, prominent scales, the intercostal spaces are wide and almost smooth to the naked eye, and tertiary costellae develop only over the ventral 10 mm of the disc. This is an exact match for the *dennanti* form. Also, AMS C92004 and C112573, both from 5 m, Portsea, Victoria, each include one large pair that is extremely coarsely and conspicuously sculptured, with wide-topped primary costae and large, wide scales all down all costal crests, long scales on secondary costae, and many scaly tertiary and quaternary costellae, but still with wide, smooth intercostal spaces, ie., these resemble the sculpture as it would be on the *dennanti* form before abrasion removed the scales from the primary costae. A scatter diagram and a histogram comparing height and length of a range of specimens of *M. asperrima* and of *M. heterophyseta* (Figs 48, 49) showed that the Werrikoo Limestone population does not fall outside the range of variation of the Recent population of the former in inflation or in numbers of costae. The thing that is unusual about the Werrikoo Limestone population, then, is its concentration of tall, narrow, coarsely sculptured shells. This seems to have some local ecological explanation, and the form does not appear to be of any taxonomic significance.

A final point about *M. asperrima* that is particularly significant for biostratigraphy is its time range and evolution. *M. asperrima* is a particularly valuable indicator of a young age in southern Australia; all but a very few specimens we are aware of are limited to rocks younger than Bairnsdalian, ie., to Late Miocene and younger rocks. The earliest stratigraphically well constrained, large population we have seen is from the Mitchellian (early Late Miocene) Tambo River Formation outcrop on the Swan Reach–Metung Road near the Princes Highway at Swan Reach, Gippsland. Most large fossil collections in Australia include specimens from this site, and they all share several early characters for *M. asperrima*:

(a) small size—not over *c.* 65 mm high, and most do not exceed *c.* 45 mm;

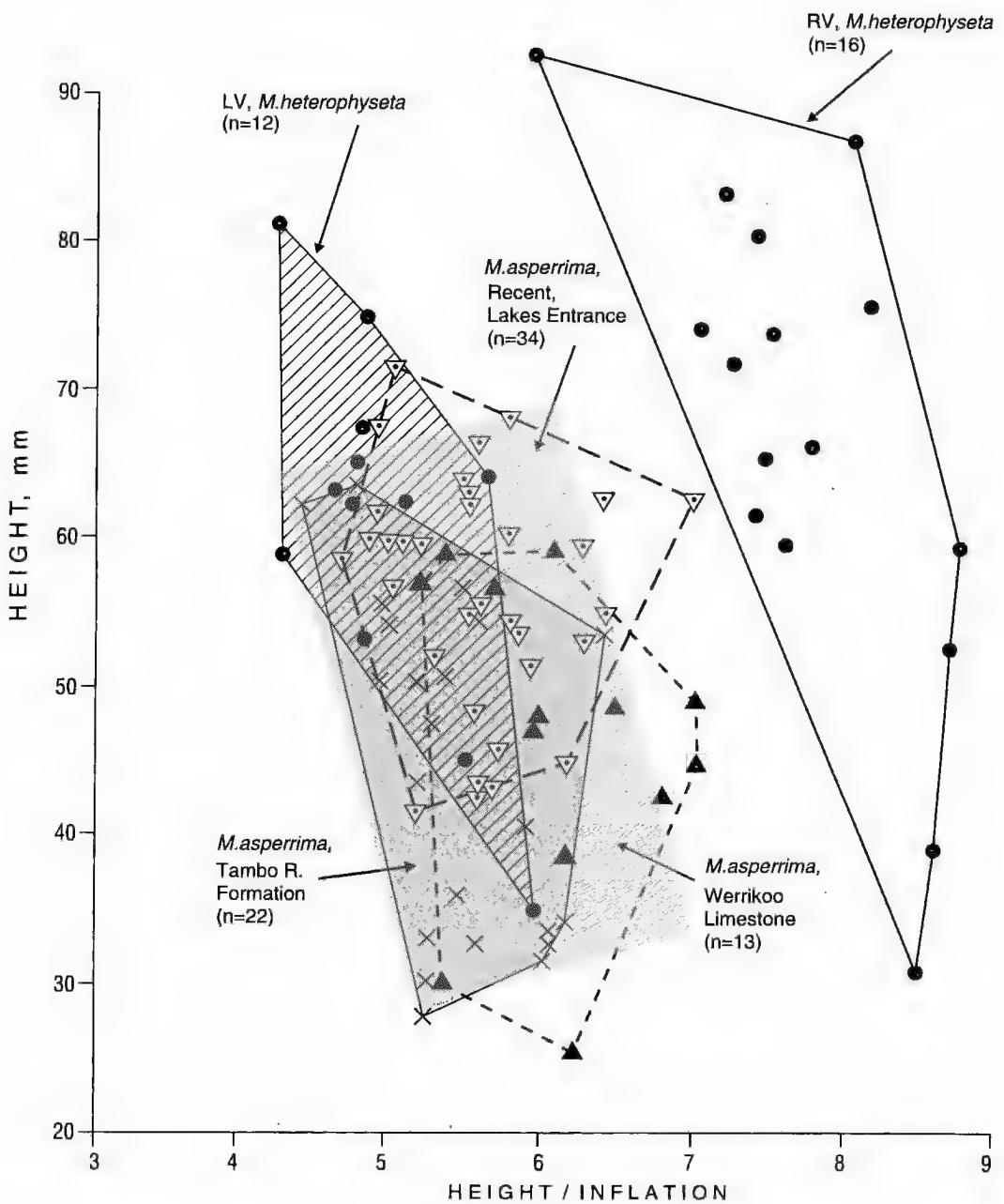


Fig. 48. Scatter diagram comparing height with relative inflation of some *Mimachlamys* populations. (A) Three populations of *M. asperrima* (Lamarck): (1) the earliest population of large, abundant specimens, in Tambo River Formation (Mitchellian) at Swan Reach, Victoria (crosses); (2) the unusually tall and narrow population in Werrikoo Limestone (Late Pliocene), Glenelg River, Victoria (inverted hollow triangles); and (3) a Recent collection in NMV from Lakes Entrance, Victoria (solid triangles). (B) These are compared with separate measurements of RVs and LVs of *M. heterophyseta* sp. nov., from Memana Formation (Early Pleistocene), Flinders Island, Bass Strait (solid circles).

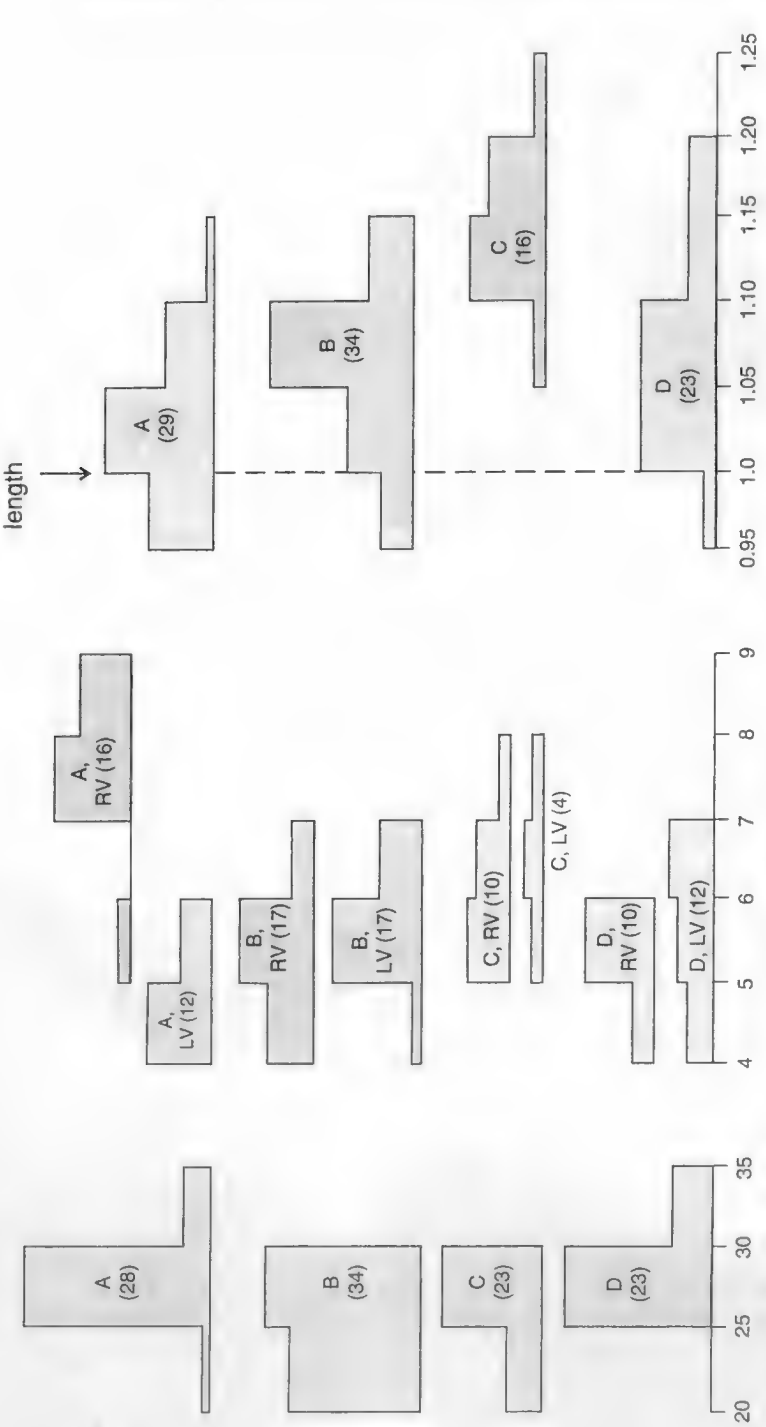


Fig. 49. Histograms of frequencies of numbers of radial costae and of relative inflation and relative length, in the same four *Mimachlamys* populations as in Fig. 48. A = *M. heterophyseta*, Memana Formation, Flinders Island; B = *M. asperrima*, Recent, Lakes Entrance, Victoria; C = *M. asperrima*, Werrikoo Limestone, Glenelg River, Victoria; D = *M. asperrima*, Tambo River Formation, Swan Reach, Victoria. All are similar in numbers of radial costae; *M. heterophyseta* is the only one with markedly different relative valve inflation in one specimen; and the Werrikoo Limestone population is markedly taller and narrower than the others.

A
B
C
D
E

(b) weak and late development of secondary and finer costellae; and
(c) small, closely spaced scales on all costellae, smaller than in the modern population of *M. asperrima*.

The very abundant specimens of *M. asperrima* from Cheltenhamian and younger rocks in the Gippsland Basin, and notably those in lower Jemmys Point Formation overlying Tambo River Formation, are all closely similar to Recent shells, and reach *c.* 70–80 mm in height.

The most useful specimens for understanding the origin of *M. asperrima* are the two assigned here that were collected from Bairnsdalian rocks: (1) NMV P301147, Fyansford Formation (here Bairnsdalian), Grice's Creek, near Frankston, Victoria, coll. T. Flannery, 1972 (1 RV, H 29.5 mm; Fig. 47B); and (2) NMV P301116, Bairnsdale Limestone (Bairnsdalian), outcrop at foot of hillside track, Myrtle Point, Mitchell River, Bairnsdale, allot. 4, sect. B, Parish of Wy Yung, Gippsland, coll. A. N. Carter, 27.iii.1957 (1 RV, H 34.8 mm; Fig. 47D). Both are unusually small for *M. asperrima*, and have all costal subdivision starting unusually well down the disc, at about two-thirds shell height. They also both have extremely low, narrow, widely spaced commarginal ridges crossing the primary costae, and no other scales present at all. All other Bairnsdalian collections of *Mimachlamys* include many quite typical specimens of *M. sturtiana*, and this is particularly common at Grice's Creek. Such specimens do not exceed *c.* 20 mm in height, and the only costal subdivision they display is very weak grooving of the primary costal edges near the ventral margin of the disc. But the only distinction between these specimens of *M. sturtiana* and *M. asperrima* is size; the Bairnsdalian specimens of *M. sturtiana* are merely small versions of the two specimens of *M. asperrima* reported here, costal subdivision commences at about the same height on all Bairnsdalian specimens, and the specimens of *M. asperrima* appear merely to have grown larger than other Bairnsdalian specimens, assigned here to *M. sturtiana*. The entire history of shells resembling *M. sturtiana*, from the Oligocene (Janjukian) specimens assigned to *M. sturtiana* to all but a few larger Bairnsdalian specimens, is of small, simply sculptured shells with little or no costal subdivision.

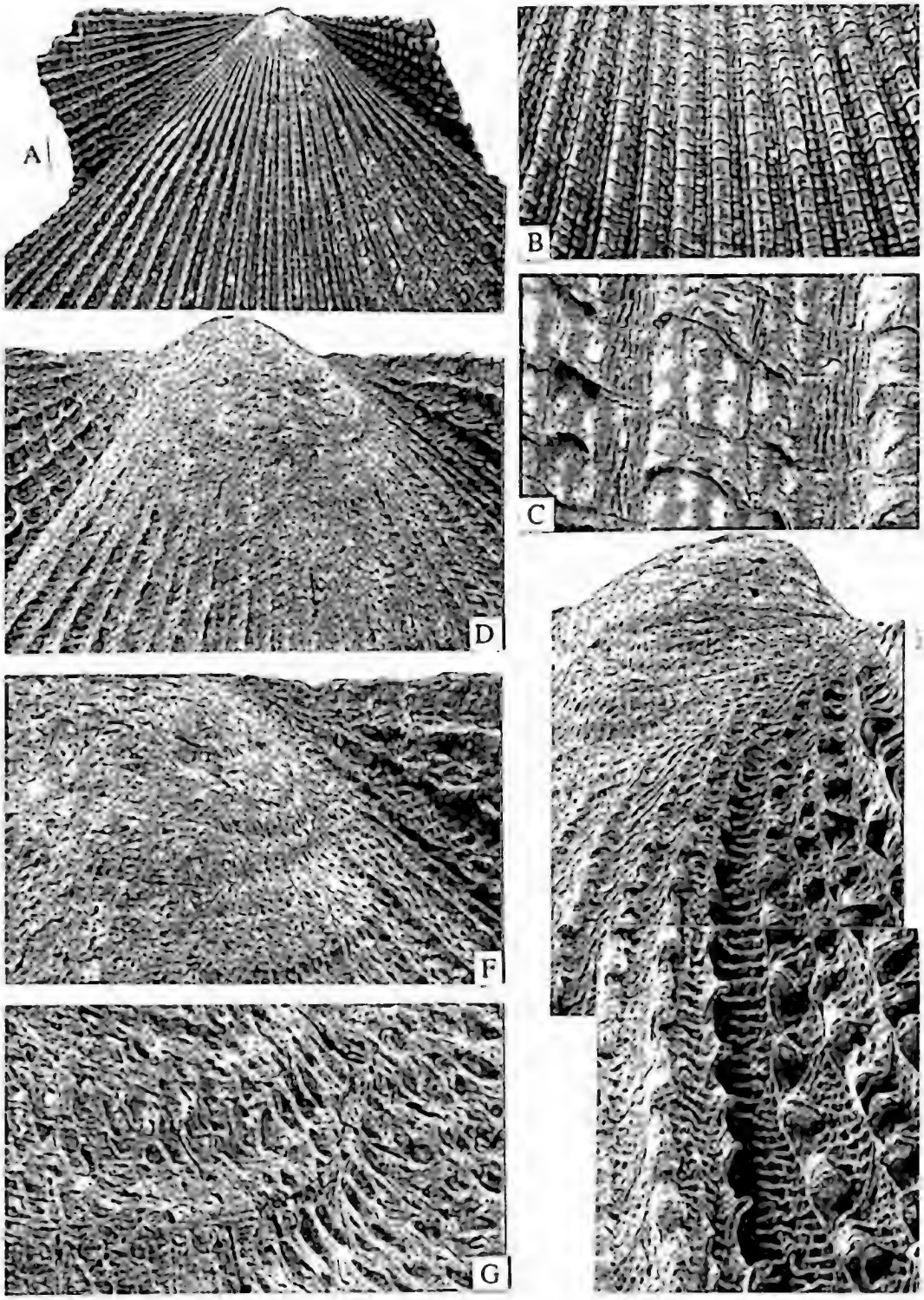
This history seems to indicate a long period (perhaps 15 my) of near-stasis in shell shape and size and in costal number (apart from the apparent evolution of finer LV preradial dissoconch sculpture during this time), followed by a relatively short period (late Bairnsdalian time only, apparently) when shell size increased dramatically, but by no means geologically instantaneously, costal subdivision initiated near the valve margin and progressed rapidly up the disc (ie., began at a smaller and smaller shell size with time) and, in short, *M. sturtiana* evolved by a rapid gradation into *M. asperrima*. The significant point is that evolution was NOT geologically instantaneous, and there is no evidence of a geographically restricted (allopatric) speciation event; rather, a single sidestep (anagenetic evolution; a random walk?) seems to have occurred over a period of perhaps 1–2 my, separating two periods of stasis. This is an unusual evolutionary mode, apparently rapid gradualism rather than a punctuational speciation event.

Mimachlamys heterophyseta sp. nov.

Figs 44A, G, 50A–E, 51A–G, 52B, D

Description. Moderately large for genus (to *c.* 112 mm high), most specimens thin and brittle for genus; disc shape moderately to strongly prosocline, length equal to or slightly greater than height; umbonal angle *c.* 90° in juvenile specimens, *c.* 110–115° in adults; inflation of LV approximately twice that of RV. LV preradial dissoconch microsculpture of deep, oval, radially elongate pits, deeper than on *M. asperrima*. Disc sculpture of 24–30 narrow, widely spaced, narrowly round-topped, rather low primary radial costae, slightly more prominent on LV than on RV of some specimens; by disc height of 5–10 mm (earlier near anterior and posterior ends than on centre of disc) fine secondary costellae subdivide from costal edges, and strengthen down disc to almost rival primary costae by ventral margin of some specimens; at *c.* 30–35 mm disc height, fine tertiary costellae initiate in same manner as secondary costellae, one in centre of

Fig. 50. Mimachlamys heterophyseta sp. nov., Memana Formation (Early Pleistocene), Flinders Island, Bass Straight. A, D, holotype, P302152, RV (A) and LV (D), from PL1206, dam on 'Brunah', Backline Road, 2.3 km NE of junction with Wingaroo Road; enlarged, × 1.25. B, E, small paratype, P302154, RV (B) and LV (E), from PL1215, dam SW side of Wingaroo Road, 1.8 km NW of junction with Melrose Road, Memana; at natural size. C, paratype, RV, P302155, from same locality as Fig.50B, E, at natural size.


A
B
C
D
F
G

radial interspace and one between each primary costa and its neighbouring secondary costa; again tertiary costellae strengthen down disc to be only slightly weaker than secondary costellae by ventral margin; on some specimens, fine quaternary costellae are initiated at various heights further down disc; secondary to quaternary costellae wide and low, filling shallowly to quite deeply concave primary radial interspaces, forming complex series of fasciculate rib groups and subgroups which, in many slightly abraded specimens, show only weak distinction between primary and lesser costae. All costal crests, on primary to quaternary costae, bearing evenly but rather widely spaced, low, ventrally cupped, ventrally directed scales. All radial interspaces sculptured with fine antimarginal ridgelets, in wavy, nearly straight groups of short ridges near centre of disc, complexly herringbone-patterned near anterior and posterior ends of disc. RV anterior auricle long and narrow, with deep, narrow byssal notch, depressed, strongly ridged byssal fasciole and functional ctenolium in large adults, ctenolium with 4 stout, hooked functional teeth; main face of auricle, above byssal fasciole, sculptured with 6–7 wide costae as on disc. LV anterior auricle moderately long, with strongly sinuous anterior margin inclined strongly towards anterior, producing moderately deep byssal sinus and obvious, strongly protruding, pointed anterior extremity, sculptured with many low, closely spaced, scaly costae resembling secondary and tertiary costellae of disc. Posterior auricles small, with posterior margin inclined strongly towards anterior and weakly concave in outline, sculptured as LV anterior auricle. Interior of ventral margin weakly sinuous, but without internal rib carinae on largest thin-shelled specimens seen; a few unusually thick-shelled specimens with short, prominent carinae around interior of ventral margin. Hinge teeth weakly developed on most specimens, with low, wide resilial teeth obvious on a few specimens.

Dimensions.

Holotype, NMV P302152	H 65.0	L 66.6	LV
	65.5	65.3	RV
Paratype, NMV P302153, PL1216	93.2	93.6	RV
Paratype			
WAM 68.1257a			
Cook's dragline	H 95.5	L 97.0	LV
WAM 89.974a, Busselton	108.1	113.8	LV
WAM 89.974b, Busselton	110.8	121.0	RV

Type material. Holotype, NMV P302152, a pair of valves, PL1206, Memana Formation (Early Pleistocene), dam C on 'Brunah' Station, Backline Road, 2.3 km NE of junction with Wingaroo (No. 2A) Road, Flinders Island, Bass Strait, grid ref. Flinders I. 915809, coll. D. M. Shanks, H. E. Wilkinson & T. A. Darragh, 4.ii.1969; one paratype, NMV P302153, Memana Formation, PL1216, dam A on 'Marapana' Station, Backline Road, 2.7 km ENE of junction with Wingaroo (No. 2A) Road, Flinders Island, grid ref. Flinders I. 926799, coll. T. A. Darragh, D. M. Shanks & H. E. Wilkinson, 5.ii.1969; 6 paratypes, NMV P302154–8, Memana Formation, PL1215, dam on SW side Wingaroo (No. 2A) Road, 1.8 km NW of junction with Melrose (No. 2) Road, Memana, Flinders Island, grid ref. Flinders I. 963815, coll. T. A. Darragh, H. E. Wilkinson & D. M. Shanks, 5.ii.1969; 10 paratypes, WAM 68.1257a–j, Memana Formation, Cook's dragline hole, Flinders Island, coll. D. G. Smith, 1968; one paratype, LV, NMV P300273, Memana Formation, PL1217, dam B, Cole's property, 'Marapana' Station, Backline Road, 2.7 km ENE of junction with Wingaroo Road, Memana, Flinders Island, gird ref. Flinders I. 927797, coll. T. A. Darragh, H. E. Wilkinson & D. M. Shanks, 5.ii.1969 (specimen studied by SEM).

Other material examined. **Early Pleistocene:** MEMANA FORMATION, FLINDERS ISLAND: PL1205, 'Brunah' B (12 specimens); PL1206, 'Brunah' B (18 specimens); PL1207, 'Brunah' D (2 specimens); PL1208, 'Brunah' E (9 specimens); PL1215, SW side Wingaroo Rd (35 specimens); PL1216, 'Marapana' A (5 specimens); PL1217, 'Marapana' B (6 specimens); PL1218, Oakenfall's (1 specimen); PL1276, 'Nangetty' (4 specimens); PL1280, G. Smith's (13 specimens); WAM 95.10, Cole's draglines 1, 2 and 3, Flinders Island (2 specimens); WAM 68.1277, Cole's dragline No. 2, Flinders Island (2 specimens); 'YOUNGER' ASCOT FORMATION, PERTH BASIN: WAM 70.1607, 27.4–29.0 m, Poletti's No. 2 bore, W side Semple Rd, Jandakot (1 specimen); WAM 72.954, 37.5 m, Jandakot Cement Works bore, Parkes Rd, Yangebup (3 specimens); WAM 74.35, 41.9–42.1 m, Paulik's bore, Semple Rd, Jandakot (5 specimens); WAM 74.613, 40.6 m in above bore (5 specimens); WAM 75.1028, 42 m in GSWA Jandakot No. 50 Exploratory Bore, Forrestdale (3 specimens); WAM 75.1086, 32.0–34.0 m, GSWA Lake Thompson

Fig. 51. Mimachlamys heterophyseta sp. nov., SEMs of relatively small, incomplete LV (H 29.4 mm, hinge length 14.8 mm), P300273, Memana Formation (Early Pleistocene), from PL1217, dam No. 17, 'Marapana', Backline Road, 2.7 km ENE of junction with Wingaroo Road, Memana, Flinders Island; enlargements of umbonal area and auricles (A × 4), of disc sculpture (B × 17, C × 100), of sculpture of preradial dissoconch (D × 20, F × 35, G × 240), and of pitted sculpture of preradial dissoconch passing into irregular 'herringbone' ridges in groove at junction of posterior auricle with disc (E × 30).

No. 200 Exploratory Bore, Orton Rd, 100 m W of Cumming Rd, Peel Estate (3 specimens); WAM 98.418, Kardinya, Melville municipal bore, spoil from 31 m in bore (1 specimen); WAM 86.927, Ascot Formation undifferentiated (Pliocene–Pleistocene?), spoil heaps at borehead, Iley's bore No. 1, corner Forrest and Warton roads, Banjup (8 specimens); WAM 72.1302, 34.8–35.1 m, Jandakot Cement Works bore, Parkes Rd, Yangebup, WA (85 fragments). **Middle Pleistocene** (oxygen isotope stage 7; G. W. Kendrick, pers. comm.): WAM 89.974, sewerage excavation in grounds of Catholic school, Kelly Drive, Busselton, Geographe Bay, WA (5 specimens); WAM 94.247, spoil from dam excavation, *c.* 3 m from surface, E side Redgum Way, Dumbarton via Busselton, WA (3 specimens); WAM 94.743, as above, 3.1–3.7 m below surface (3 specimens); WAM 95.8, as above (2 specimens); WAM 95.9, as above (8 specimens). **Recent:** WAM S12615, Cockburn Sound, S of Fremantle, WA, coll. L. Marsh & A. Paterson, 1971 (1 specimen, both valves, mottled paler and darker purplish pink); WAM S12616, dredged, Cockburn Sound, WA, Harry Baker Collection, donated 1983 (2 live-collected, articulated specimens, small (*c.* 50 mm high), uniform pale cream, with coarse scales and a prominent secondary costa on each side of each primary costa, similar to specimens from the Ascot Formation, beneath Perth); WAM S12376, Middleton Beach, Albany, south coast of WA, coll. by E. H. Sedgwick, 1929–1982 (16 LVs and 5 RVs, beach-abraded, apparently all *M. heterophyseta*; purple and brick-red through to yellow, some with radial costae darker than their interspaces); WAM S12377, Sta. 13, W of City Beach, north of Fremantle, WA, coll. by L. M. Marsh on FRV *Flinders*, 12.x.1974 (2 valves, pale purplish pink, with 3 small valves of *M. asperrima*.

Occurrence and time range. Apparently restricted to Early Pleistocene to Recent; Memana Formation on Flinders Island, Bass Strait, and 'younger' Ascot Formation in boreholes in the Perth Basin, Western Australia; late Middle Pleistocene (oxygen isotope stage 7) deposits around Geographe Bay, southern Western Australia; living around southwestern Western Australia, at least from Fremantle to Albany. Potentially of biostratigraphy utility.

Remarks. Specimens of *M. asperrima* are present in the same collections as *M. heterophyseta* sp. nov., in most cases. *Mimachlamys heterophyseta* sp. nov. was first distinguished from *M. asperrima* by the much greater inflation of the LV than of the RV and, with only RVs in some collections, by the narrower primary radial costae and the much greater number of lesser costae and costellae filling each radial interspace. Other significant differences that help distinguish the two are the markedly more strongly prosocline shape, the thinner shell of Early Pleistocene specimens with (correspondingly?) even weaker traces of internal rib carinae around the ventral margin, and the much less obvious hinge teeth of *M. heterophyseta* than of *M. asperrima*. Specimens from water bores around Perth ('younger' Ascot Formation) are mostly small, not over about 50 mm high, and RVs predominate over LVs, presumably reflecting sizes and shapes that survive percussion drilling; the small RVs tend to have their primary costae a little abraded, so that much of the radial sculpture is similar in prominence, or at least with the three main costae of each fasciculate group similar in height. The late Middle Pleistocene material from near Busselton, Geographe Bay, includes larger specimens, a few with thicker shells than any of the other material, and a few thick-shelled specimens have short but prominent carinae inside the ventral margin (Fig. 44G), again helping to confirm a position in *Mimachlamys*.

A scatter diagram and a histogram (Figs 48, 49) comparing height with valve inflation in *M. heterophyseta* and *M. asperrima* clearly bring out the difference in inflation. The comparison shows that the RV in *M. asperrima* is slightly more inflated than the LV, whereas the RV is slightly less inflated in *M. heterophyseta* than in *M. asperrima*, and the LV is very much more inflated in *M. heterophyseta* than in *M. asperrima*. No really small specimens were available of *M. heterophyseta* unabraded enough for SEM examination, so a relatively large shell (H 29.5 mm; NMV P300273) was examined, and found to display the pitted preradial microsculpture well in the hollows between the umbonal area and the auricles (Fig. 51C, E–G). This confirms a position in *Mimachlamys* for a species whose relationships were previously obscure to us, because of the lack of internal rib carinae in almost all specimens. However, as noted above, a few of the late Middle Pleistocene specimens of *M. heterophyseta* sp. nov. from near Busselton, Geographe Bay, have thicker shells than the rest, and have short but prominent carinae inside the ventral margin.

At a late stage in this research we realised that it was likely that *M. heterophyseta* is extant around southern Australia, as all other pectinids known to us in the Pleistocene fauna of southern Australia are still living. Mrs S. M. Slack-Smith (Malacology, Western Australian Museum) kindly searched the Museum's collections of Recent specimens identified as *Mimachlamys asperrima*, and recognised the four lots of Recent *M. heterophyseta* listed above (Fig. 52B, D). It is likely that these few specimens do not represent the full modern geographic range of the species, although it is quite feasible that the formerly widespread *M. heterophyseta* has become limited to southern Western Australia since the Middle Pleistocene.

Careful examination of more collections from southern Australia may help to clarify the present geographic range of this species.

The two small, uniform cream, coarsely sculptured specimens in WAM S12375 (dredged, Cockburn Sound, Western Australia) are live-collected examples of the form identified as *M. heterophyseta* from Ascot Formation in the many water bores in the Perth Basin (listed above). Their coarse sculpture and cream coloration raise the possibility that they may represent yet another, consistently small (to *c.* 50 mm high), previously unrecognised species of *Mimachlamys*, but more Recent material will be needed to verify that. Identification as *M. heterophyseta* is maintained at present.

Etymology. The specific name (Greek, '*heteros*', different +'*physetos*', blown or inflated) refers to the strongly discrepant inflation that characterises this species.

Mimachlamys funebris (Reeve, 1853)

Fig. 47E

Pecten funebris Reeve, 1853: pl. 22, fig. 85.
Chlamys funebris; Wells & Bryce, 1985: 160, pl. 60, fig. 588.
Chlamys (Mimachlamys) funebris; Rombouts, 1991: 28, pl. 11, fig. 2a.
Mimachlamys funebris; Waller, 1991: 32; Lamprell & Whitehead, 1992: pl. 9, fig. 54.

Remarks. A single rather small specimen from a Late Pleistocene deposit at Shark Bay, Western Australia is referred to *Mimachlamys funebris* (Reeve), which in the Recent fauna inhabits this same area, the central and northern coasts of Western Australia. It is taller and narrower than *M. asperrima*, with 26 wide, prominent, round-topped radial costae, many widely spaced, low, V-shaped, ventrally cupped scales on the costae, a single narrow secondary costella on the side of each primary costa that faces the centre of the disc, and prominent internal rib carinae over the distal quarter of the disc.

Dimensions. WAM 79.2127 H 45.3 L 40.3

Type material. Not seen; presumably in BMNH; from Bathurst Island, northern Western Australia.

Other material examined. WAM 79.2127, lower shell-bed, Dampier Formation (Late Pleistocene), 3 km S of Broadhurst Bight, Peron Peninsula, Shark Bay, Western Australia, coll. W. J. E. van de Graaff & G. W. Kendrick, 14.xi.1977 (1 LV). This is the only fossil record of this species we are aware of. The age and stratigraphy of the locality of this specimen and most of the material of the following species were described by Kendrick (1990).

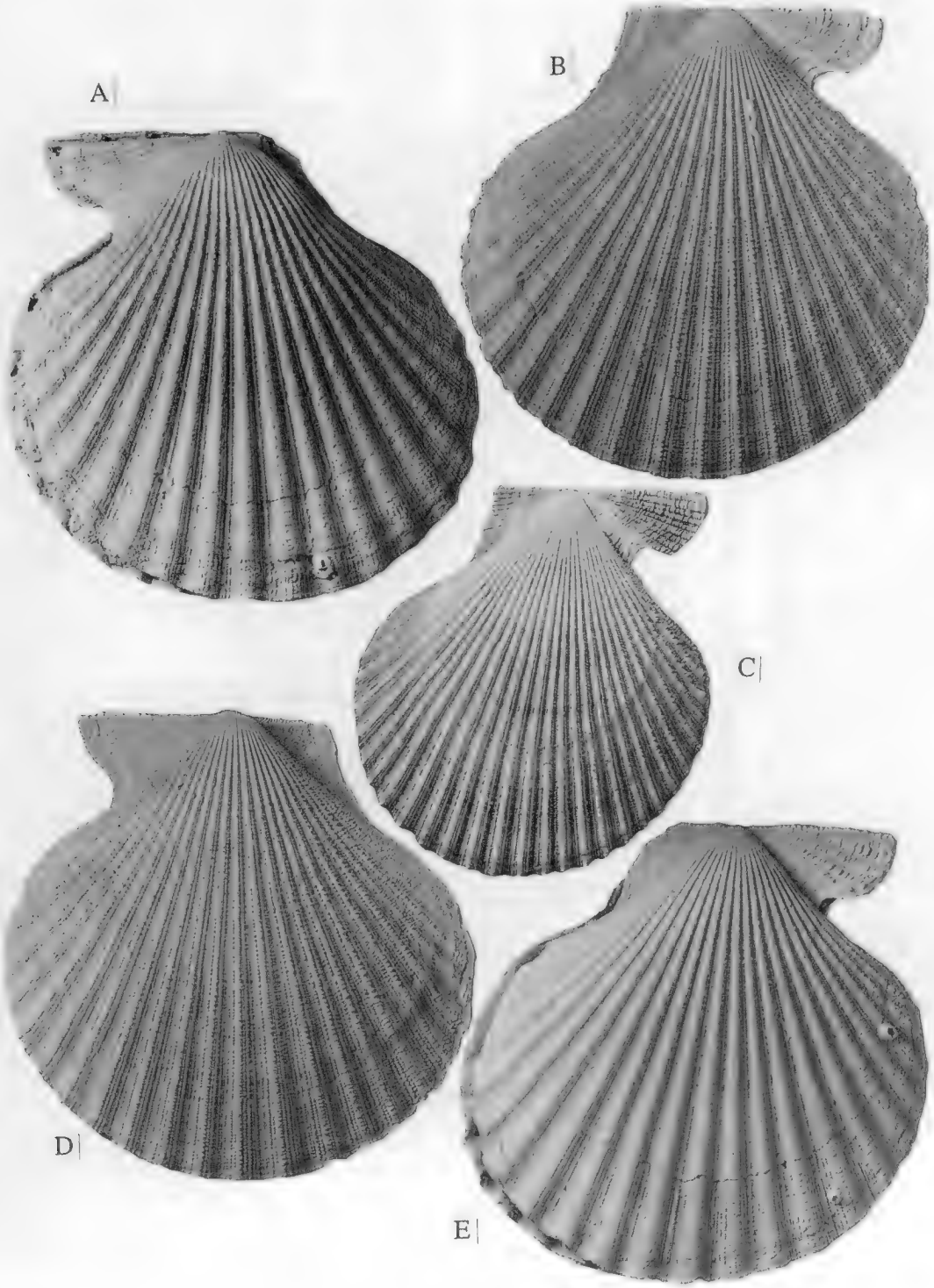
Mimachlamys sp. nov.?

Fig. 52A, E

Mimachlamys australis; Cotton, 1961: 105, fig. 91 (?not *Pecten australis* G. B. Sowerby II, 1842, = *P. asperrimus* Lamarck).
Chlamys australis; Wells & Bryce, 1985: 158, pl. 60, fig. 583 (?not *Pecten australis* G. B. Sowerby II, 1842).
Chlamys (Mimachlamys) australis; Rombouts, 1991: 27, pl. 10, fig. 4; pl. 28, fig. 6a (?not *Pecten australis* G. B. Sowerby II, 1842).
Mimachlamys australis; Lamprell & Whitehead, 1992: pl. 9, fig. 55 (?not *Pecten australis* G. B. Sowerby II, 1842).

Remarks. This is the species known in the Australian literature and in shell identification guides as *Chlamys australis* (G. B. Sowerby II, 1842). The type material of *Pecten australis* G. B. Sowerby II (1842: 76, pl. 19, figs 219, 220) is from 'Swan River', Western Australia, and, as the species usually known as *C. australis* occurs only further north, in the Shark Bay area of north-central Western Australia, it is not surprising that *P. australis* proves to be a synonym of *Mimachlamys asperrima* (Lamarck) (Dr T. R. Waller 1998, pers. comm.). Dr T. R. Waller has informed us that, if this is a species distinct from *M. asperrima* rather than a northern ecomorph limited to Shark Bay and further north, it requires a new name. It obviously would be preferable to base a new name on Recent material, however, and this is outside the scope of the present paper.

Mimachlamys sp. nov.? is similar to *M. asperrima* in many characters, and we are unclear whether they are distinct species. *Mimachlamys* sp. nov.? reaches a significantly larger size (to *c.* 120 mm high, rather than the 90 mm or, rarely, 100 mm reached by typical southern Australian *M. asperrima*), is a little narrower (ie., shorter in relation to height) than in *M. asperrima*, and the primary radial costae are higher, wider and more evenly rounded in cross-section than in *M. asperrima*, with lower and narrower, more closely spaced, much more finely spinose secondary and tertiary costellae in the radial interspaces and, consequently, a less strongly spinose general appearance than in *M. asperrima*. The most marked difference is that all auricles of *Mimachlamys* sp. nov.? are a little larger than in *M. asperrima*, the anterior auricles are obviously longer in *Mimachlamys* sp. nov.? than in *M. asperrima*, the anterior ends of the


A
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anterior auricles are more narrowly pointed, and the posterior margins of the posterior auricles are more strongly concave in outline in *Mimachlamys* sp. nov.? than in *M. asperrima*. A further distinction is that internal rib carinae are long and prominent in *Mimachlamys* sp. nov.?, occupying about a third to half of disc height, whereas they are scarcely discernible in *M. asperrima*. The range of variation of these characters needs to be examined in Recent populations before it is clear whether this form is a distinct species or is a variant of *M. asperrima*.

Dimensions. WAM 84.1491, Dampier Formation, Shark Bay H 103.8 L 101.2

Type material. *Pecten australis* G. B. Sowerby II, 1842, type material not seen; in BMNH (Dr T. R. Waller, pers. comm.); from 'Swan River', Western Australia.

Other material examined. **Late Pleistocene:** WAM 70.2683, gully W side Marsh Hill, Lyndon River, near discharge into Lake MacLeod, N of Shark Bay, grid ref. Minilya 168063 (1 specimen); WAM 79.2003, Dampier Limestone, lower shellbed; Broadhurst Bight, Peron Peninsula, Shark Bay, WA (1 specimen); WAM 84.978, erosion scarp, N side of claypan, 2 km N of Yaringa–Gladstone track, Yaringa Station, WA (1 specimen); WAM 84.1491, Dampier Formation, lower shellbed, 3 km S of S end of Broadhurst Bight, Peron Peninsula, Shark Bay, WA (1 specimen).

Occurrence and time range. *Mimachlamys* sp. nov.? lives now from Bluff Point, just south of Kalbarri, to Derby, on King Sound, Western Australia (Wells & Bryce 1985: 158) but is common only in Shark Bay, Western Australia. The Late Pleistocene fossils reported here also are all from the Shark Bay–Lake Macleod area.

Tribe Decatopectinini Waller, 1986

Remarks. A diagnosis is provided above, under 'Classification'. Waller (1986) included in Tribe Decatopectinini the genera *Anguipecten* Dall, Bartsch & Rehder, 1938, *Annachlamys* Iredale, 1939, *Bractechlamys* Iredale, 1939, *Decatopecten* Rüppell in Sowerby 1839 (= *Comptopallium* Iredale, 1939), *Excellichlamys* Iredale, 1939, *Flexopecten* Sacco, 1897, *Gloripallium* Iredale, 1939, *Juxtamusium* Iredale, 1939, *Mirapecten* Dall, Bartsch & Rehder, 1938, and *Somalipecten* Waller, 1986. Although all of these genera, except *Flexopecten* and *Somalipecten*, occur now in tropical northern Australia, *Annachlamys* is the only member of the tribe with a fossil record in southern Australia.

Two tribes of Pectininae are characterised by having microsculpture of only commarginal lamellae on the radially sculptured dissoconch: Palliolini Waller, 1993 and Decatopectinini. Palliolini differ from Decatopectinini mainly in having distinctive, widely spaced commarginal lamellae (5–15 per 2 mm interval in centre of disc, 10 mm from umbo, compared with 30–70 per 2 mm interval), in not having the distinctive, very weakly inflated LV umbonal area of Decatopectinini, in not having such numerous hinge teeth as in Decatopectinini, although dorsal and intermediate teeth still predominate, and in having the byssal notch fairly shallow throughout ontogeny, and virtually lost altogether in adults of some taxa. So, although the common Australian fossil *Annachlamys murrayana* (Tate) has far-set commarginal lamellae over most of the adult disc, not unlike the far-set commarginal lamellae characteristic of *Mesopeplum* (Tribe Palliolini), it is the close-set commarginal lamellae present on the early costate part of the disc and between areas of far-set lamellae further down the disc that express its phylogenetic relationships.

Genus ***Annachlamys*** Iredale, 1939

Annachlamys Iredale, 1939: 358.

Type species (by original designation). *Pecten leopardus* Reeve, 1853 (= *Pecten flabellatus* Lamarck, 1819), Recent, Indo-West Pacific.

Remarks. *Annachlamys* is characterised by its short, wide aequipectinoid shape (length exceeds height significantly in all species, and the umbonal angle is moderately high in juvenile and very high in adult specimens), by the curved dorsal disc margins and flared, rather elongate anterior and posterior ends of the disc, by the low, wide auricles with only a very shallow byssal notch (although a row of ctenolial teeth remaining in the groove between the RV anterior auricle and the disc indicates that a functional ctenolium is present in juvenile specimens), by having almost no LV byssal

Fig. 52. A, E, *Mimachlamys* sp. nov.?, Shark Bay, WAM 84.1491, lower shellbed, Dampier Limestone (Late Pleistocene), Peron Peninsula, 3 km S of S end of Broadhurst Bight, Shark Bay, Western Australia; an articulated pair, LV (A) and RV (E), reduced to × 0.67. B, D, *Mimachlamys heterophyseta* sp. nov., Recent, WAM S12615, Cockburn Sound, S of Fremantle, Western Australia; RV (B) and LV (D) of an articulated pair, enlarged, × 1.25. C, *Mimachlamys asperrima* (Lamarck), holotype of *Chlamys asperrima dennanti* Gatliff & Singleton, RV, P13503, Werrikoo Limestone (Late Pliocene), Glenelg River, SW Victoria; at natural size.

sinus and almost vertical, straight anterior and posterior margins to the auricles, by the radial sculpture of *c.* 20–30 low, wide, evenly rounded costae with, on most species, interspaces each a mirror image of a costa, by its commarginal sculpture of low, fine, close-set lamellae early on the disc and, in most species, its later development of additional more prominent, far-set lamellae over the central and distal disc and auricles, by its extremely weak LV preradial microsculpture of shallow, antimarginally elongate pits, passing out into narrow antimarginal ridgelets in the area of costal inception and then fading out, by its very prominent, sharply defined internal rib carinae, and by its hinge with rather low, narrow, dorsal and intermediate teeth. Living species have a brilliant color pattern, the white shell being brightly splashed with large orange and/or red maculations.

Dijkstra (1995: 485, pl. 20, figs 83–86) discussed and illustrated the lectotype of *Pecten flabellatus* Lamarck, type species of *Annachlamys*, and designated its type locality as Shark Bay, Western Australia.

Only two species of *Annachlamys* (and a possible third, unnamed) are known fossil in southern Australia, and the younger of them, *A. murrayana* (Tate), is last known in upper Fyansford Formation and Port Campbell Limestone (Bairnsdalian, late Middle Miocene), so the genus and tribe appear to have retreated from southern Australia to the tropical north as sea temperatures fell after the late Early–early Middle Miocene climatic optimum of Neogene times.

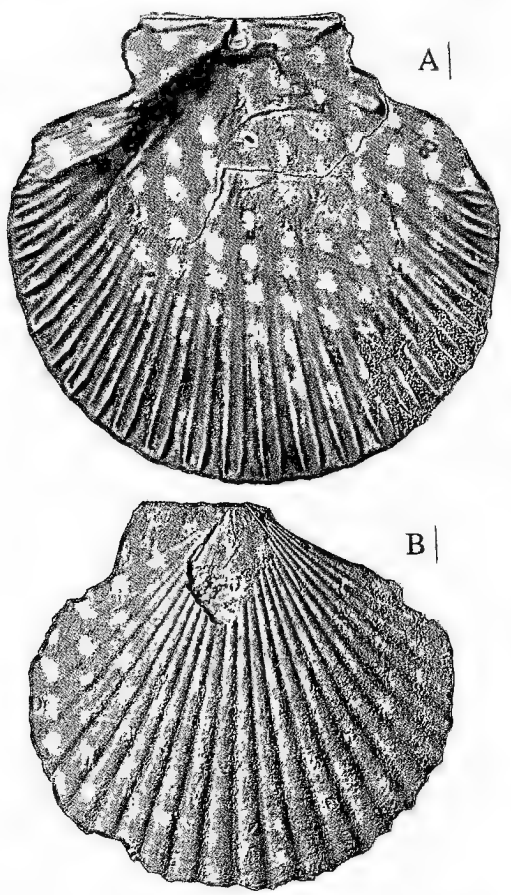


Fig. 53. A, *Annachlamys rhipidata* sp. nov., holotype, RV, interior of P300478 (exterior in Fig. 54C), Jan Juc Formation (Janjukian), Bird Rock Cliffs, Torquay, Victoria; enlarged, × 1.25. B, *Annachlamys* sp. nov.?, WAM 62.164, incomplete RV, Abrakurrie Limestone (Longfordian), Madura (North) Cave, Nullarbor Plain; enlarged, × 1.25.

Annachlamys rhipidata sp. nov.

Figs 53A, 54C–E

Description. Moderate-sized for genus (to *c.* 60 mm long), length exceeding height significantly in all specimens, umbonal angle *c.* 125°; acline to very weakly prosocline; weakly inflated, LV umbonal area slightly less inflated than RV umbonal area. Anterior, ventral and posterior disc margins an even, regular curve. RV disc sculptured with 22–29 low, wide, rather weakly defined radial costae with narrow interspaces, each interspace about one third width of one costa; entire disc and auricles sculptured with fine, low, closely spaced commarginal lamellae, abraded off crests of costae near centre of disc on many specimens. LV disc sculptured with a corresponding number of narrow, widely spaced, narrowly rounded radial costae with shallowly concave sides, each costa about one-third width of one interspace; a few specimens with one or two secondary costae intercalated in one or two interspaces; closely covered with commarginal lamellae as on RV. RV anterior auricle with weakly sinuous anterior margin inclined slightly towards anterior, without byssal fasciole or ctenolium, byssal notch very shallow; row of small ctenolial teeth remaining in groove between RV anterior auricle and disc on well preserved specimens, indicating that ctenolium is functional until about third to half adult size; RV posterior auricle with slightly convex posterior margin inclined slightly towards anterior. LV auricles with lightly convex anterior and posterior margins, each slightly inclined towards umbo; each auricle sculptured with 4–5 low, narrow, widely spaced radial costae and

many closely spaced commarginal lamellae. Interior with prominent rib carinae, arranged clearly in pairs on edges of internal expression of radial costae, in distal area of disc forming a thin, raised ridge on each carina. Hinge with low, narrow teeth, one pair of narrow dorsal teeth and one pair of intermediate teeth.

Dimensions.

Holotype, NMV P300478	H 47.2	L 50.3	RV
Paratype, NMV P302135 Bird Rock	50.5	57.4	LV
Paratype, NMV P302136 Bird Rock	53.4	58.1	LV

Type material. Holotype, NMV P300478, Jan Juc Formation (Janjukian), coastal section south of Bird Rock, Torquay, Victoria, coll. R. Wilkins; 2 paratypes, NMV P302135–6, Jan Juc Formation (Janjukian), 'Bird Rock ledge', coastal section at Torquay, Victoria, coll. F. A. Cudmore.

Other material examined. **Janjukian:** CALDER RIVER LIMESTONE: Aw3 and Aw4, anticline on Aire coast (1 specimen); Aw3, Aire coast (1 specimen); Calder River, Horden Vale (2 specimens); Spud Point, Glenaire (2 specimens); CLIFTON FORMATION: Kawarren lime quarry (3 specimens); W of Princetown (4 specimens); base of limestone overlying conglomerate, 0.8 km NW of Point Ronald, Princetown (1 specimen); JAN JUC FORMATION: PL3024, Bird Rock, Torquay (17 specimens); PL3025, Fishermans Steps, Torquay (1 specimen); Spring Creek, Torquay (6 specimens); Torquay (7 Specimens); WAURN PONDS LIMESTONE: Waurn Ponds (26 specimens); Ceres (1 specimen); PL3279, Blue Circle old pit (10 specimens); POINT ADDIS LIMESTONE: PL3227, Point Addis (10 specimens); Aireys Inlet (1 specimen); WAM 85.438, 50 m E of steps, SW corner of Point Addis (1 specimen). **Longfordian:** MANNUM FORMATION: PL3184, quarry at Taworri (13 specimens); PL3187, quarry at Younghusband (10 specimens); PL3192, road cutting, Punthari (2 specimens); PUEBLA FORMATION: Ad6, mouth of Spring Creek, Torquay (4 specimens); ZEALLY LIMESTONE: yellow polyzoal limestone between Torquay village and Jan Juc Creek (1 specimen).

Occurrence and time range. Janjukian and Longfordian. Most records are from Torquay, Victoria, or from Mannum Formation, Murray Basin. As *A. rhipidata* is easily distinguished from *A. murrayana*, it is potentially of high biostratigraphic utility.

Remarks. *Annachlamys rhipidata* sp. nov. differs markedly from *A. murrayana* in a number of prominent characters: its lesser inflation; its much less obvious flattening of the umbonal area of the LV; its equal inflation of the two valves, rather than the RV being much the more inflated, as in *A. murrayana*; its slightly less rectangular auricles; most clearly, in having discrepant sculpture on the two valves, rather than identical sculpture as in *A. murrayana*; and in having only the fine, close, low commarginal sculpture characteristic of the Decatopectinini, and not the much more prominent, high, widely spaced commarginal lamellae of *A. murrayana*.

Annachlamys murrayana succeeds *A. rhipidata* abruptly in Batesfordian rocks and, possibly in Longfordian rocks, at one Gippsland locality. These two species are so dissimilar that an ancestor-descendent relationship between them appears unlikely; ie., the abrupt replacement did not result from a speciation event. Rather than indicating that the replacement was diachronous, the few Longfordian records of *A. murrayana* in Gippsland seem more likely to suggest that the replacement of *A. rhipidata* by *A. murrayana* occurred during Longfordian time.

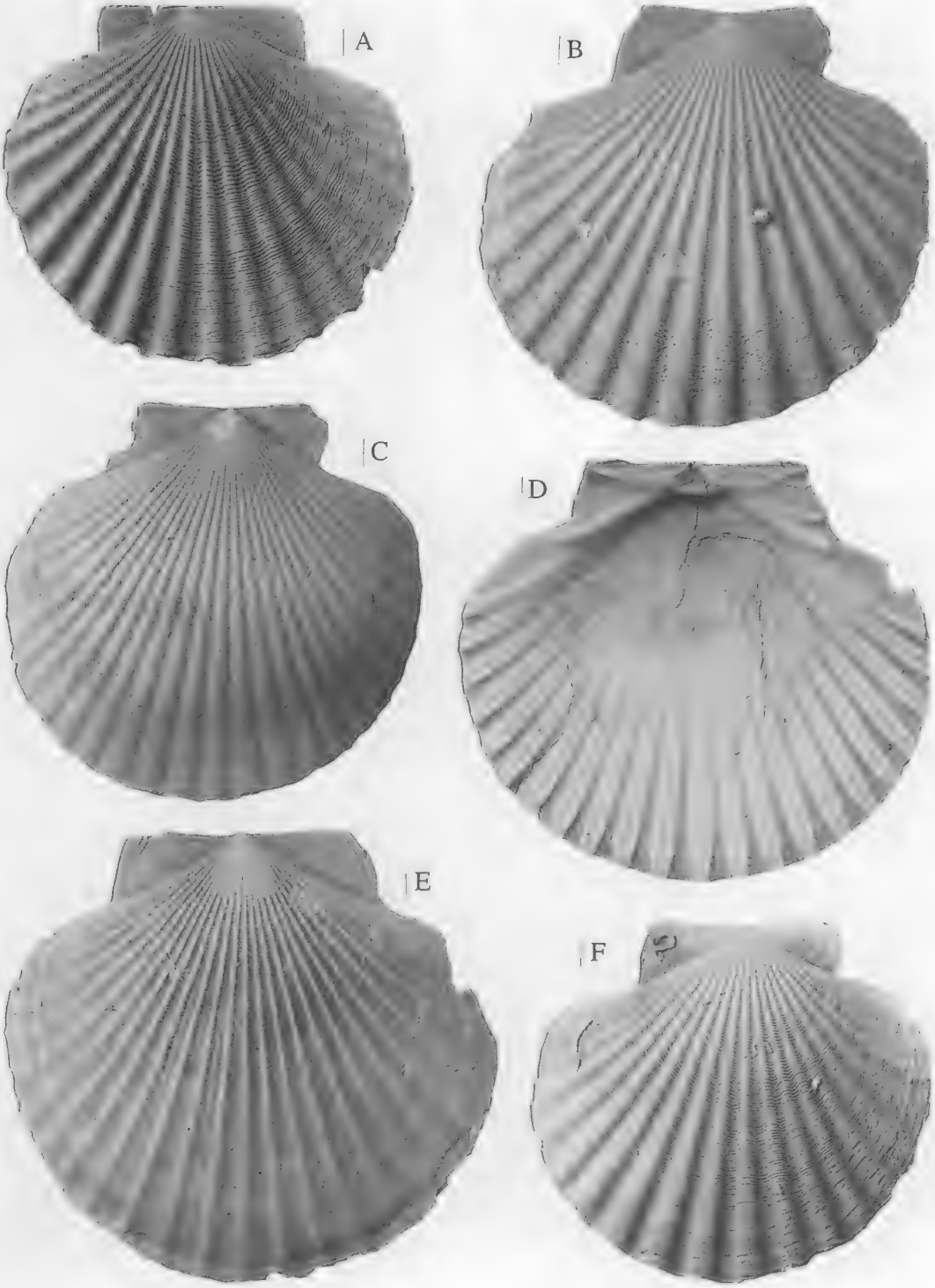
Etymology. The specific name (Greek '*rhipis*', a fan) refers to the unusual, discrepant radial costae of this species.

Annachlamys murrayana (Tate, 1886)

Figs 54A, B, F, 55A–H

Pecten murrayanus Tate, 1886: 108, pl. 8, fig. 5a, b; Tate & Dennant, 1893: 224; Ludbrook, 1973: pl. 26, fig. 74.
Pecten murrayensis [*sic*]; Tate, 1899: 270.
Pecten murrayana; Ludbrook, 1969, fig. 96.5.

Description. Moderate-sized (length 55–65 mm), length markedly exceeding height in large specimens; acline to weakly prosocline; umbonal angle wide (*c.* 105° on juvenile specimens, increasing to *c.* 125°); moderately inflated, RV much more strongly inflated than LV, LV with particularly flat umbonal area; valves gaping slightly at anterior and posterior ends of articulated specimens. Exterior sculpture of 18–22 very regular, even, equally spaced radial costae of low, rounded section, with interspaces each a mirror image of a costa in section, continuing strongly across entire disc, identical on the two valves; crossed by very numerous high, extremely thin commarginal lamellae, outer ends of lamellae of unabraded specimens turning down towards venter; between lamellae, another series of much finer, lower and closer lamellae present, filling commarginal interspaces. RV anterior auricle with very shallow, weakly and evenly concave byssal notch, outline evenly convex above; ctenolial teeth remaining in groove between RV anterior auricle and disc,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indicating ctenolium is functional until about a third to half adult size; LV auricles almost symmetrical, posterior slightly higher than anterior, both sloping weakly towards anterior, with rounded dorsal corners; RV posterior auricle identical to LV one; weak radial costae present on proximal area of auricles, fading out distally. Interior with very prominent, sharply defined internal rib carinae. Hinge with thin, weakly defined dorsal and intermediate teeth only.

Dimensions.

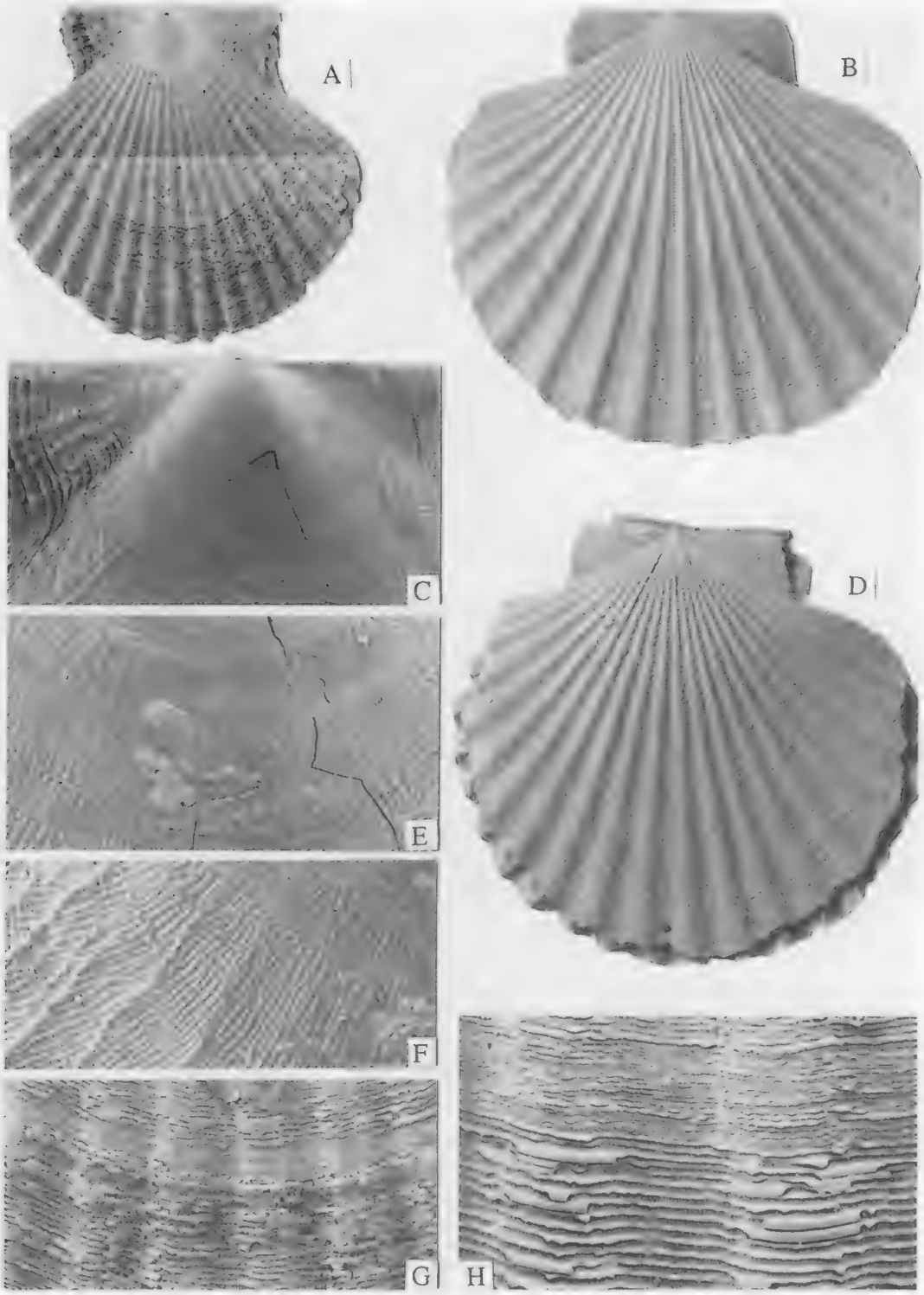
Lectotype, SAM T955A	H 43.3	L 45.0	2 valves
Paralectotype, SAM T955C	39.6	42.7	RV
Paralectotype, SAM T953B	44.4	48.2	LV
Paralectotype, SAM T953C	41.5	44.7	RV
NMV P300368, PL3098 Bairnsdalian	53.4	59.5	LV

Type material. Lectotype of *Pecten murrayanus* Tate, 1886, designated here, Tate's (1886: pl. 7, fig. 5a, b) figured syntype pair, SAM T955A, with four paralectotypes, SAM T955B–E, all glued to one block, labelled 'Eocene, Middle Murrayvian, Blanchetown', ie., from Morgan Limestone (Balcombian) at Blanchetown, Murray River; SAM T953A–H, 8 paralectotypes (much better preserved than figured syntype), from Muddy Creek Marl (Balcombian), Muddy Creek, near Hamilton, western Victoria.

Other material examined. **Longfordian:** GIPPSLAND LIMESTONE: PL3255, Darriman Quarry (4 specimens). **Batesfordian:** BATESFORD LIMESTONE: Batesford (8 specimens); new quarry, Batesford (9 specimens); upper quarry, Batesford (8 specimens); Batesford filter quarry (7 specimens); E side of Batesford quarry (4 specimens); Batesford quarry (4 specimens); Moorabool River valley (1 specimen); FLINDERS LIMESTONE: PL3055, Flinders (1 specimen); WUK WUK MARL: PL3054, Skinners (5 specimens); 3 m above bridge on E side of Boggy Creek, near Bairnsdale (2 specimens); PL3252, Brock's Quarry, Longford (19 specimens). **Balcombian:** BOCHARA LIMESTONE: Grange Burn, 100 m downstream from natural arch (1 specimen); CADELL MARL: PL3084, Cadell Marl lens (18 specimens); FYANSFORD FORMATION: PL3069, Red Bluff, Shelford (3 specimens); PL3070, Farrels (8 specimens); PL3071, SW of Glenleigh (8 specimens); PL3072, Fyansford (22 specimens); PL3074, Dingley Shaft (8 specimens); PL3077, Altona Bay coal shaft (6 specimens); Balcombe Bay (3 specimens); Meredith (2 specimens); E of baths, Beaumaris (1 specimen); clay below low tide, between baths and boatshed, Beaumaris (3 specimens); Shelford (2 specimens); Moorabool River (1 specimen); cement works, Fyansford (2 specimens); 21 m in MMBW sewer tunnel, Sussex St to North Rd, Brighton (1 specimen); MORGAN LIMESTONE: PL3189, Mannum pumping station road cutting (7 specimens); PL3198, Blanchetown bridge cutting (43 specimens); PL3202, Adams St, Blanchetown (2 specimens); PL3203, South Australian Water Ski Assoc. (17 specimens); PL3205, Woods Flat Post Office (19 specimens); PL3208, Murray cliffs, Great Yarra Reach (6 specimens); PL3211, Murray cliffs, 'Karelia' (5 specimens); PL3214, 3.5 km SE of Cadell (1 specimen); PL3215, Murray cliffs, 'Nikalepko' (3 specimens); PL3217, Murray cliffs, 'Yarra View' (4 specimens); PL6668, Overland Corner (3 specimens); Morgan (76 specimens); Tate's bed 9, 6.4 km below Morgan (8 specimens); AMS F5886, cliff 72, Parish of Hay, Murray River (1 specimen); AMS F5884, cliff 44, Parish of Waikerie, Murray River (2 specimens); AMS F5885, cliff 39, Hart's Reach, Murray River (2 specimens); MUDDY CREEK FORMATION: PL3082, Clifton Bank, Muddy Creek (270 specimens); Muddy Creek, near Hamilton (277 specimens); beneath nodule bed at McDonald's Bank (age and stratigraphy unknown) (7 specimens); Grange Burn, 100 m E of section 2 on Gill's map (5 specimens); AMS, Muddy Creek (42 specimens); AMS F1722, Muddy Creek, 'named by Prof. R. Tate and may be regarded as his co-type; pres. Prof. R. Tate, 1892' (5 specimens); NULLARBOR LIMESTONE: WAM G4029–4030, Ooldea, Nullarbor Plain (2 specimens; one is identical to normal *A. murrayana*); GIPPSLAND LIMESTONE (Balcombian): PL3273, railway cutting, Newmerella (17 specimens); Newmerella (18 specimens). **Bairnsdalian:** FYANSFORD FORMATION: PL3098, Native Hut Creek (2 specimens); PL3100, Murgheboluc 4A (1 specimen); PORT CAMPBELL LIMESTONE: Warrnambool (1 specimen); PATA LIMESTONE: PL3213, Ramco Point (1 specimen).

Occurrence and time range. Longfordian (in Gippsland); Batesfordian to Bairnsdalian. Most records are Balcombian, as *A. murrayana* is common in Morgan Limestone on the Murray River and abundant in Muddy Creek Formation at Muddy Creek, near Hamilton. Excellent, typical specimens occur at Brock's Quarry and Darriman Quarry, near Longford (Longfordian) but there are no other records before Batesfordian, and *A. murrayana* seems to have replaced *A. rhipidata* abruptly. Typical specimens occur in several Batesfordian

Fig. 54. A, B, F, *Annachlamys murrayana* (Tate): A, F, P300368, PL3098, Fyansford Formation (Bairnsdalian), Native Hut Creek, 200 m S of bridge on Geelong–Inverleigh Road, Victoria; LV (A) and RV (F) of one specimen, at natural size; B, one of Tate's unfigured paralectotypes of *Pecten murrayanus*, SAM T953C, RV, from Muddy Creek Formation (Balcombian), Muddy Creek, near Hamilton, western Victoria; enlarged, × 1.5. C–E, *Annachlamys rhipidata* sp. nov., from Jan Juc Formation (Janjukian), Bird Rock Cliffs, Torquay, Victoria; all enlarged, × 1.25: C, holotype, RV exterior, P300478 (interior in Fig. 53A); D, paratype, RV interior, P302135; E, paratype, LV exterior, P302136.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limestone outcrops in Gippsland also. Bairnsdalian specimens are known from very few localities, but a few specimens have been examined from the youngest part of Fyansford Formation and from Port Campbell Limestone. Thereafter, *Annachlamys* disappeared from the fossil record of southern Australia, except for Late Pleistocene and Holocene occurrences in the Perth and Carnarvon basins, Western Australia.

Remarks. The evenly and regularly, coarsely costate radial sculpture, identical on the two valves, the even, widely spaced coarser series of commarginal lamellae, the weakly inflated LV and particularly flattened LV umbonal area, the much more strongly inflated RV, the narrow, indistinct dorsal and intermediate hinge teeth, and the very shallow byssal notch show that this is a typical species of *Annachlamys*, closely resembling the tropical living type species, *A. flabellata* (Lamarck). It differs from *A. flabellata* in its smaller size (to *c*. 65 mm long; *A. flabellata* reaches 100 mm: AMS C119782, 60 m, off Tin Can Bay, Queensland), in having an evenly curved margin, without the rather elongate, laterally extended anterodorsal and posterodorsal margins of *A. flabellata*, and in maintaining the prominence of the radial costae down the whole height of the disc, rather than the costae becoming lower and wider down the disc as in *A. flabellata*. Differences from *A. rhipidata* are pointed out above.

Annachlamys sp. nov.?

Fig. 53B

?*Pecten murrayanus*; Ludbrook in Lowry, 1970: fig. 27H, I (not *Pecten murrayanus* Tate, 1886).

?*Chlamys (Annachlamys)* aff. *murrayana*; McNamara & Kendrick, 1994: 18, fig. 8B.

Remarks. Two specimens from Poivre Formation of Barrow Island, northern Carnarvon Basin, Western Australia (McNamara & Kendrick 1994: 18), a single one from Abrakurrie Limestone at Madura, southeastern Western Australia, and a LV and a RV from Abrakurrie Limestone illustrated by Ludbrook (in Lowry 1970: fig. 27H, I) appear to belong in a species distinct from both *A. rhipidata* and *A. murrayana*. These specimens are a little more anteroposteriorly elongate than either *A. murrayana* or *A. rhipidata*, and lack radial costae on the auricles, or at least, on the posterior auricle, the only one present on both the specimen figured by McNamara & Kendrick (1994: fig. 8B) and the Abrakurrie Limestone specimen; note, however, that costae appear to be absent from both auricles on both the RV and LV in material illustrated by Ludbrook (in Lowry 1970: fig. 27H, I). Also, the radial costae are lower, wider and more numerous in this species (26–31 in Poivre Formation specimens, 25 in WAM 62.164; approximately 25–26 major ones in the illustrations by Ludbrook in Lowry 1970: fig. 27H, I) than in *A. murrayana* and *A. rhipidata*. The surface of the present species appears smooth to the unaided eye, but under moderate magnification is seen to be closely crowded with very fine, closely spaced commarginal ridgelets, as in *A. rhipidata*. One Abrakurrie Limestone specimen (WAM 62.164) has slightly wider intercostal spaces than that illustrated by McNamara & Kendrick (1994: fig. 8B), but the specimens illustrated by Ludbrook (in Lowry 1970: fig. 27H, I) appear to be closely similar to that from the Poivre Formation. More material is needed before the characters and variation of this apparently further unnamed species are clear.

Dimensions. WAM 62.164 H 40.4 L 44.1 mm

Material examined. WAM 62.164, Abrakurrie Limestone (Longfordian), Madura Cave North, 30 m below surface, Nullarbor Plain, coll. P. Cawthorn, 5.i.1962 (1 RV). Two specimens (1 RV and 1 LV) were recorded also by McNamara & Kendrick (1994: 18) from Poivre Formation (Middle Miocene, by large Foraminifera; Chaproniere 1975), Barrow Island, Western Australia (WAM 82.551), and two specimens (again, 1 RV and 1 LV) were illustrated from Abrakurrie Limestone, Eucla Basin, by Ludbrook (in Lowry 1970: fig. 27H, I): Firestick Cave (fig. 27H) and Murra-el-elevan Cave (fig. 27I). More

Fig. 55. *Annachlamys murrayana* (Tate). A, C, E–H, SEMs of small LV, P4302, Fyansford Formation (Balcombian), Balcombe Bay, Mornington, Victoria: A, whole shell, enlarged, × 3.8 (H 13.4 mm); C, E, F, enlargements of sculpture of preradial dissoconch (C × 25, E × 50) and at costal inception (F × 50), showing weakly pitted early sculpture passing down into antimarginal ridgelets; G (× 10), H (× 25), enlargements of disc sculpture towards ventral margin. B, another of Tate's (1886) unfigured paralectotypes (see also Fig. 54B) of *Pecten murrayanus*, SAM T953B, an LV from Muddy Creek Formation (Balcombian), Muddy Creek, near Hamilton, western Victoria; enlarged, × 1.5. D, LV of Tate's figured syntype (an articulated pair), here designated lectotype of *Pecten murrayanus* Tate, SAM T955A, 'Eocene, Middle Murrayvian, Blanchetown', ie., Morgan Limestone (Balcombian) at Blanchetown, Murray River, South Australia; enlarged, × 1.5.

than one species might well be represented by this material, in view of the difference in age between Abrakurrie Limestone (Late Oligocene–Early Miocene) and Poivre Formation (Middle Miocene), but much more material is needed from both areas before this possibility can be evaluated.

Tribe Palliolini Korobkov in Eberzin, 1960

Remarks. A diagnosis is provided above, under 'Classification'. The major genus of this tribe in Australia and New Zealand is *Mesopeplum*. Beu (1995) showed that *Mesopeplum* underwent a significant evolutionary radiation in New Zealand during Middle Miocene to Early Pliocene time, giving rise to at least six other genera (*Sectipecten* Marwick, 1928; *Phialopecten* Marwick, 1928; *Kaparachlamys* Boreham, 1965; *Borehamia* Beu, 1978; *Towaipecten* Beu, 1995; and at least one other genus still unnamed). However, none of these genera has ever reached Australia. One possible minor offshoot from *Mesopeplum* in Australia is represented by *Mesopeplum*(?) *contrainflatum* sp. nov., but this is not well enough known to justify a separate genus at this time. The sole Australian member of Tribe Palliolini recognised herein remains *Mesopeplum*.

The endemic New Zealand genus (or subgenus) *Borehamia* Beu, 1978 differs from *Mesopeplum*, *sensu stricto* in its large size [adults of the youngest species, *B. crawfordi* (Hutton, 1873) reach 125 mm in height], in its more prominent radial plicae, in its very strongly discrepant valve inflation (the LV being almost flat and the RV strongly inflated, particularly near the umbo) and, in particular, in its small, almost equal auricles of nearly square outline, with a very shallow, scarcely discernible byssal notch in large specimens. The other common and widespread genus of this group in New Zealand is *Phialopecten* Marwick, 1928. This differs from *Mesopeplum* in its larger size (adults of the mid-Pliocene to Late Pliocene species reach *c.* 180 mm in length), in its less prominent and more widely spaced commarginal lamellae, in lacking the large, shell-folding radial plicae of *Mesopeplum* (although the rather prominent, narrow, numerous radial costae may in fact fold the shell wall and satisfy the definition of plicae in many specimens), in its considerably larger auricles with a wide functional byssal notch and ctenolium in small specimens but a shallow notch and no functional ctenolium in adults, and in its consistent radial sculpture of prominent costae (or narrow plicae, in many specimens) each subdivided into 3 costellae in the LV and into 2 costellae on the RV of most species (costal subdivision is more complex in some species). The result is a shell that, in superficial characters, resembles a large *Mimachlamys* species or a strongly costate *Placopecten* species, rather than a descendent of *Mesopeplum*.

Genus ***Mesopeplum*** Iredale, 1929

Mesopeplum Iredale, 1929a: 162.

Type species (by original designation, Iredale 1929a: 188). *Mesopeplum caroli* Iredale, 1929 (= *Chlamys fenestrata* Hedley, 1901), Recent, from temperate Western Australia, around southern Australia and Tasmania to southern Queensland.

Dendopecten Hertlein, 1936: 26.

Type species (by original designation). *Pecten dendyi* Hutton, 1902, Early Pliocene, Momoe-a-toa Shellbed, Chatham Island.

Remarks. *Mesopeplum* is characterised by its small to moderately large size (most species *c.* 30–60 mm high, a few to 100 mm), its few, prominent plicae bearing simple, weakly subdivided radial costae, its LV preradial dissoconch bearing unusually coarsely reticulate sculpture of prominent commarginal ridges crossing relatively few, widely spaced antimarginal ridgelets, which fade out rapidly once the costae are initiated, by almost all taxa having the RV strongly inflated and the LV weakly inflated, particularly at the umbo, by having prominent internal rib carinae around the ventral margin, and by having microsculpture, after costal inception, solely of prominent, widely spaced commarginal lamellae. In unabraded specimens of many species, the outer edges of the commarginal lamellae turn over to form flanges parallel to the shell surface, and unite across the interspaces to form another type of secondary shell surface remarkably similar in outward appearance to that formed by coarse shagreen microsculpture in some Chlamydini.

Mesopeplum is second only to *Talochlamys* as the most speciose genus of Australian Cenozoic scallops. Many species have particularly short ranges, and so are of high biostratigraphic utility, although in many species this is greatly lessened by restricted environments or restricted geographic ranges; eg., *M. gambierense* is abundant in, but apparantly limited to, Gambier Limestone and Naracoorte Limestone in the Otway Basin.

At present, it seems to be correct to include only the following Australian species and the New Zealand fossil and living species (listed by Beu & Maxwell 1990: 395) in the genus *Mesopeplum*. It should be noted, though, that a few possibly related fossil species occur in Argentina. '*Myochlamys*' [invalid name] *deseadensis* Ihering (1907: 410,

pl. 15, fig. 102) and, in particular, '*M.*' *laziarina* Ihering (1907: 409, pl. 16, figs 103, 104), both from the Middle–Late Miocene 'entreriense' formation of the Deseado area, Golfo San Jorge, Patagonia, resemble *Mesopeplum* species in many characters. Ihering (1907: 410) specifically described the 'petites lamelles concentriques' [commarginal lamellae] and internal rib carinae of '*Myochlamys*' *deseadensis*, and it is clear at least that these species belong in Tribe Palliolini. Although these species have major, prominent radial plicae, they are fewer, lower and wider than in any species we assign to *Mesopeplum*, and they differ further from Australasian *Mesopeplum* species in having larger auricles and a much larger byssal notch. We have not seen material of these Argentinian species, but it seems likely that they belong in a genus of Palliolini, other than *Mesopeplum*.

Mesopeplum gambierense (Tenison Woods, 1865)

Fig. 56H–K

Pecten coarctatus?; Tenison Woods, 1862: 76, unnumbered fig.; 255 (not *Pecten coarctatus* Born, 1778).
Pecten gambierensis Tenison Woods, 1865: 1, fig. 2; Tate, 1886: 112.

Description. Small (to *c.* 30–35 mm high), highly inflated, RV much more strongly inflated than LV; strongly prosocline; umbonal angle moderate, *c.* 100°. Exterior sculptured with 5 very weak plicae, fading out after proximal third of disc on RV, extending further down disc but fading out before ventral margin on most LVs; and with 30–35 very prominent radial costae, particularly prominent, with sharply defined margins and wider than their interspaces on RV, high but narrower than their interspaces on LV, costal crests bearing prominent, large, ventrally cupped, quadrate to hemispherical scales on RV and shorter, ventrally cupped scales on LV; interspaces crossed by obvious, coarse commarginal ridges. Auricles small, sculptured as on neighbouring disc; RV anterior auricle short, narrow, with moderately deep, narrow byssal notch, functional ctenolium and deeply depressed byssal fasciole in adults; LV anterior auricle with weakly sinuous anterior margin sloping strongly towards anterior; posterior auricles very short, with moderately strongly concave to weakly sinuous posterior margins, sloping strongly upwards towards anterior. Interior corrugate, with weak rib carinae around ventral margin. Hinge weak, with narrow dorsal teeth and one pair of short, moderately prominent resilial teeth.

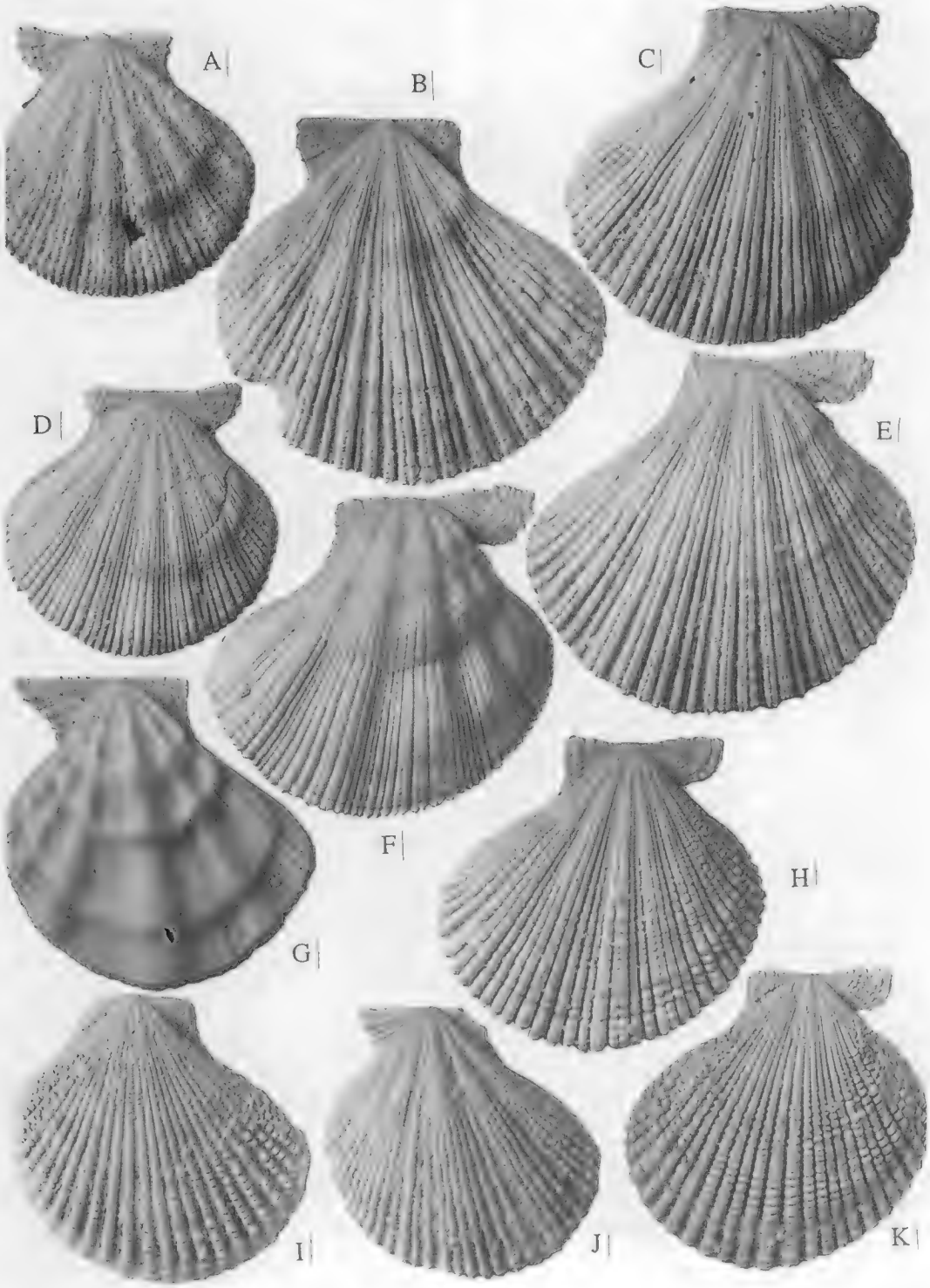
Dimensions.

Neotype, NMV P302125	H 30.5	L 30.5	RV
NMV P302126, locality as neotype	29.7	30.4	LV

Type material. As noted above under *Semipallium foulcheri*, Tenison Woods' (1865) type specimens have been lost, and all four species require neotypes. Tenison Woods (1865) said of *M. gambierense* that 'it may be said to be the characteristic shell of the formation [Gambier Limestone]. There are few places in it where some specimens are not found; but it is especially abundant in the lower strata at Beswick's Cave, Mount Gambier, and on the walls of the caves at Mosquito Plains.' We have therefore regarded the probable type locality as Beswick's Cave (now known as Town Cave), within the township of Mount Gambier, but unfortunately, although *M. gambierense* is common in outcrops within the cave, we were unable to collect good, complete specimens from this cave or from any locality close to Mount Gambier, and designate as neotype the best RV available to us. Neotype, designated here: NMV P302125, RV (Fig. 56K), from Gambier Limestone (Longfordian), PL3222, small lime pit 1.5 km north of mouth of Dry Creek and 1 km north of Donovans—Princess Margaret Rose Cave Road, *c.* 0.5 km west of Victorian–South Australian border, southeastern South Australia, grid ref. Gambier 965960, coll. P. A. Jell, 22.iii.1982.

Other material examined. **Longfordian:** GAMBIER LIMESTONE: PL3219, Nelson North Rd quarry (26 specimens); PL3221, mouth of Dry Creek (8 specimens); PL3222, lime pit 1.5 km N of mouth of Dry Creek (137 specimens); PL3224, 0.4 km N of mouth of Dry Creek (41 specimens); PL3225, quarry S of 'Honeysuckle' (34 specimens); PL3227, entrance to Amphitheatre Cave (19 specimens); PL3228, Glenelg River between Dry Creek and Reed Bed (22 specimens); PL3230, ACI lime quarry (53 specimens); PL3235, Gambier Earth Movers quarry (22 specimens); PL3241, Telford's fish ponds (1 specimen); PL3242, pit on Telford's fish farm (16 specimens); PL3244, council quarry, Smith's property, Port MacDonell (1 specimen); Mount Gambier (23 specimens); Umpherston's Cave, Mt Gambier (4 specimens); Glenelg River cliff opposite mouth of Dry Creek (77 specimens); NARACOORTE LIMESTONE: PL3245, Comaum Forest quarry (64 specimens); PL3246, Elderslee Quarry (56 specimens); PL3247, James Quarry (20 specimens); PL3248, Henske's Quarry (194 specimens); Gunnett's Well, Parish of Meercek, 68 chains ENE of junction of Naracoorte and Apsley roads (1 specimen); quarry on SA–Victorian border, 17 chains N of Apsley–Naracoorte Rd, Parish of Boikerbert (6 specimens); AMS, Naracoorte (3 specimens). **Batesfordian:** GAMBIER LIMESTONE: PL3236, pit on McLean's Rd (4 specimens).

Occurrence and time range. Limited to Gambier and Naracoorte limestones, of Longfordian and Batesfordian age. Common to abundant in most outcrops of these formations throughout the district from Naracoorte to Port MacDonell, southeastern South Australia, and contiguous areas in Victoria,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but we have seen no specimens nor any other species resembling it from any other locality in Australia or New Zealand.

Remarks. *Mesopeplum gambierense* is one of the most distinctive species of the genus, easily recognised by its rather small size (to *c*. 35 mm high), its very strongly inflated RV and more weakly inflated LV, its strongly prosocline shape, its plicae being weakly defined on the RV or even, in some specimens, virtually absent from both valves but, in most specimens, moderately prominent on the LV, its radial sculpture of simple, undivided, well elevated costae, wide and closely spaced on the RV and narrow and more widely spaced on the LV, and in particular by its unique costal sculpture of large, quadrate to hemispherical, ventrally cupped scales, on most specimens much larger and more obvious on the RV than the LV.

Tenison Woods' (1865: fig. 2) original lithograph of *Pecten gambierensis* clearly shows the large scales, the strongly prosocline shape, the low plicae over the proximal area of the disc, and the narrow byssal notch in the RV anterior auricle. Unlike the other illustrations on this plate, though, this image is left–right reversed, ie., the lithographer did not draw it in reverse so that it would print correctly.

Mesopeplum minimum sp. nov.

Fig. 56A, C, D

Description. Small for genus, to *c*. 26 mm high; the two valves about equally inflated; weakly to moderately prosocline; umbonal angle 100–105°. LV preradial sculpture not seen. Plicae low, narrow, regular and even, indistinctly margined; 7–8 on most specimens; 1 or 2 growth ledges present on most specimens. Radial sculpture of numerous narrow, well elevated costae, each interspace narrower than one costa on plical crests and about the width of one costa in plical interspaces; plicae and radial costae closely similar on the two valves. Entire surface sculptured with narrow, far-set commarginal lamellae, raised into low scales on costal crests of most specimens. RV anterior auricle small, narrow, with deep, narrow byssal notch, narrow, depressed byssal fasciole and functional ctenolium in adults, ctenolium with 4–5 very small, narrow teeth, situated on thin, raised ridge extending alongside byssal fasciole; anterior margin of auricle rounded, inclined towards anterior, dorsal margin weakly serrated; main face of auricle above byssal fasciole sculptured with 4–5 prominent, scaly radial costae. LV anterior auricle small, triangular, anterior margin weakly sinuous, inclined very strongly towards anterior, sculptured with 5–6 radial costae as on RV auricle. Posterior auricles very small, triangular, coarsely sculptured, with concave posterior margin inclined weakly towards anterior. Interior almost smooth, weakly plicate, with prominent, very short, very narrow carinae around outermost ventral margin only. RV hinge with long, narrow dorsal teeth and one pair of small, narrow, widely diverging resilial teeth alongside dorsal half of resilifer; LV hinge with long, narrow infradorsal teeth and narrow, obvious sockets for resilial teeth.

Dimensions.

Holotype, NMV P302101	H 25.3	L 26.2	RV
Paratype, NMV P302802 PL3212, Cave Cliffs	19.8	19.9	2 valves
Paratype, NMV P302798 as above	21.4	22.8	LV
Paratype, NMV P302799 as above	16.9	16.7	RV
Paratype, NMV P302800 as above	14.5	15.1	LV
Paratype, NMV P302801 as above	10.0	9.7	LV

Type material. Holotype, NMV P302101, Mannum Formation (Longfordian), PL3212, cliff on right bank Murray River, from top of cliffs to 10 m above water, 'Cave Cliffs' Station, 8.5 km southwest of Overland Corner, South Australia, grid ref. Pooginook 305185, coll. A. G. Beu & T. A. Darragh, 29.ix.1993; with 10 paratypes, NMV P302798–P302802, all data as for holotype.

Fig. 56. A, C, D, *Mesopeplum minimum* sp. nov., Mannum Formation (Longfordian), PL3212, Murray River cliff on 'Cave Cliffs', 8.3 km SW of Overland Corner, South Australia, enlarged, × 2: A, LV, and D, RV, paratype, articulated pair, P302802; C, holotype, an unusually large RV, P302101. B, E–G, *Mesopeplum incertum* (Tenison Woods), Morgan Limestone (Balcombian), PL3214, Murray River cliff, 3.5 km SE of Cadell, South Australia; enlarged, × 1.5: B, large LV, P302100; E, neotype of *Pecten incertus* Tenison Woods, large RV, P300904; F, strongly convex RV, P302097; G, small LV with weak radial sculpture but many prominent ledges, P302099. H–K, *Mesopeplum gambierense* (Tenison Woods), all enlarged, × 1.5: H, RV, and J, LV, P302128a, b, Naracoorte Limestone (Longfordian), PL3248, Henske's Quarry, Naracoorte, South Australia; I, LV, P302126, and K, RV, P302125, K here designated neotype of *Pecten gambierensis* Tenison Woods, Gambier Limestone (Longfordian), PL3222, pit 1 km N of Donovan's Princess Mary Rose Cave Road, near Donovan's, southwestern South Australia.

Other material examined. **Longfordian:** GAMBIER LIMESTONE: Glenelg River cliff opposite mouth of Dry Creek (2 specimens); Glenelg River cliff 0.8 km from McEacheron Cave (1 specimen); GIPPSLAND LIMESTONE: Longford (1 specimen); MANNUM FORMATION: PL3188, Mannum pumping station (12 specimens); PL3190, Underwood Rd cutting (1 specimen); PL3191, cutting, Klose Rd, 6 km NE of Mannum (2 specimens); PL3192, Wongulla Rd cutting (2 specimens); PL3195, Swan Reach, SA (4 specimens); PL3196, Big Bend Reserve (4 specimens); PL3199, Murray cliffs, 'Cooinda' (9 specimens); PL3212, Murray cliffs, 'Cave Cliff' (11 specimens); lower beds, Murray cliffs at Wongulla (1 specimen); lower beds, Murray cliffs, Wongulla to Mannum (1 specimen); lower beds, River Murray cliffs, Overland Corner (7 specimens); Murray cliffs opposite centre of entrance to lagoon, Punyelroo (1 specimen); WAM 90.86, Mannum Motel gardens (2 specimens); WAM 93.486, Blanchetown, River Murray (1 specimen); PUEBLA FORMATION: cliff between Spring Creek and Bird Rock, Torquay (2 specimens); polyzoal limestone, beach N of Bird Rock, Torquay (34 specimens); mouth of Jan Juc Creek (16 specimens); Bird Rock cliffs, Torquay (4 specimens); ZEALLY LIMESTONE: Jan Juc Point, mouth of Spring Creek, Torquay (7 specimens); GIPPSLAND LIMESTONE: PL3252, Brock's Quarry (1 specimen); PL3253, McColl's Quarry (3 specimens). **Batesfordian:** BATESFORD LIMESTONE: bottom of new quarry, Batesford (2 specimens); Batesford filter quarry (1 specimen).

Occurrence and time range. Longfordian to Batesfordian. Moderately common in Longfordian limestones along the Torquay coast of Victoria, and in Mannum Formation (Longfordian), Murray River. Two specimens from Gambier Limestone (Longfordian) near Mount Gambier have slightly more numerous plicae and ledges than the rest of the material referred here, but seem to be conspecific.

Remarks. Mesopeplum minimum sp. nov. differs markedly from *M. incertum* in a number of characters. It has finer radial costae, most specimens are less prosocline in shape, it reaches a much smaller maximum size (H = 25 mm, compared with 45 mm in *M. incertum*), it has the two valves about equally inflated rather than the RV being much more strongly inflated than the LV as in *M. incertum*, and the whole appearance of the shell is markedly different from that of *M. incertum* because of the lower, narrower and more numerous plicae, which have a heightened effect on the appearance because of the much smaller shell size. Despite these differences, the auricles and the ctenolium are closely similar to those of *M. incertum*, although the ctenolium is situated on a much lower smooth, raised costa than in *M. incertum*. Although *M. minimum* occurs consistently in older rocks than *M. incertum* in both South Australia and Victoria, and they do not overlap in time range, the differences between them are so marked that it seems unlikely that they have an ancestor–descendent relationship.

Etymology. The specific name (Latin, '*minimus*', smallest, least) refers to this being the smallest Australian species of the genus.

Mesopeplum incertum (Tenison Woods, 1865)

Fig. 56B, E–G

Pecten coarctatus(?); Sturt, 1833, vol. 2: 254, pl. 3, fig. 13 (not *Pecten coarctatus* Born, 1778).

Pecten incertus Tenison Woods, 1865: 1, fig. 1.

Pecten polymorphoides; Tate, 1886: 113, pl. 8, fig. 2; Tate & Dennant, 1893: 224; Harris, 1897: 316; Dennant & Kitson, 1903: 120 (not of Zittel, 1864; New Zealand).

Description. Moderately large for genus, to *c.* 45 mm high; length exceeding height in large specimens; moderately to highly inflated, RV markedly more inflated than LV; moderately to quite strongly prosocline; umbonal angle moderate, 90–100°; many specimens with few to many obvious to very prominent growth ledges; with 5–7 plicae, most specimens with 5–6 relatively weak, wide ones on RV and 6–7 slightly more prominent, narrow ones on LV. Exterior sculptured with *c.* 35–50 moderately narrow to moderately wide radial costae, subdividing and intercalating irregularly across disc, many specimens with finer, lower and more closely spaced costae on LV than on RV; on many specimens costae rendered irregularly scaly by high, thin lamellae developed from commarginal ridges on costal crests; on some specimens lamellae fused over costal crests to form secondary shell surface. RV anterior auricle long and narrow compared with other auricles, with narrowly pointed anterior margin inclined upwards strongly towards anterior, with deep, narrow byssal notch, with deeply depressed byssal fasciole, and with prominent ctenolium raised above disc surface on strongly elevated, narrow ridge; main auricular face above byssal fasciole very coarsely sculptured with 5–6 narrow, strongly raised, coarsely scaly radial costae; LV anterior auricle moderately tall, with weakly sinuous anterior margin inclined moderately to very strongly towards anterior, with sharply pointed anterodorsal extremity in some specimens, bearing prominent radial costae; posterior auricles very small, narrow, with weakly concave posterior margins inclined towards anterior, prominently sculptured as other auricles. Interior well thickened, most specimens

plicate but weakly corrugated to almost smooth, with short, prominent rib carinae around ventral margin. Hinge with weak, thin dorsal teeth and one pair of prominent, thick resilial teeth in RV, and one pair of moderately prominent resilial teeth in LV.

Dimensions.

Neotype, NMV P300904	H 35.7	L 38.3	RV
NMV P302097			
Murray cliffs SE of Cadell	32.2	35.0	RV
NMV P302098, as above	38.5	40.1	RV
NMV P302099, as above	31.4	31.0	LV
NMV P302100, as above	37.8	40.0	LV

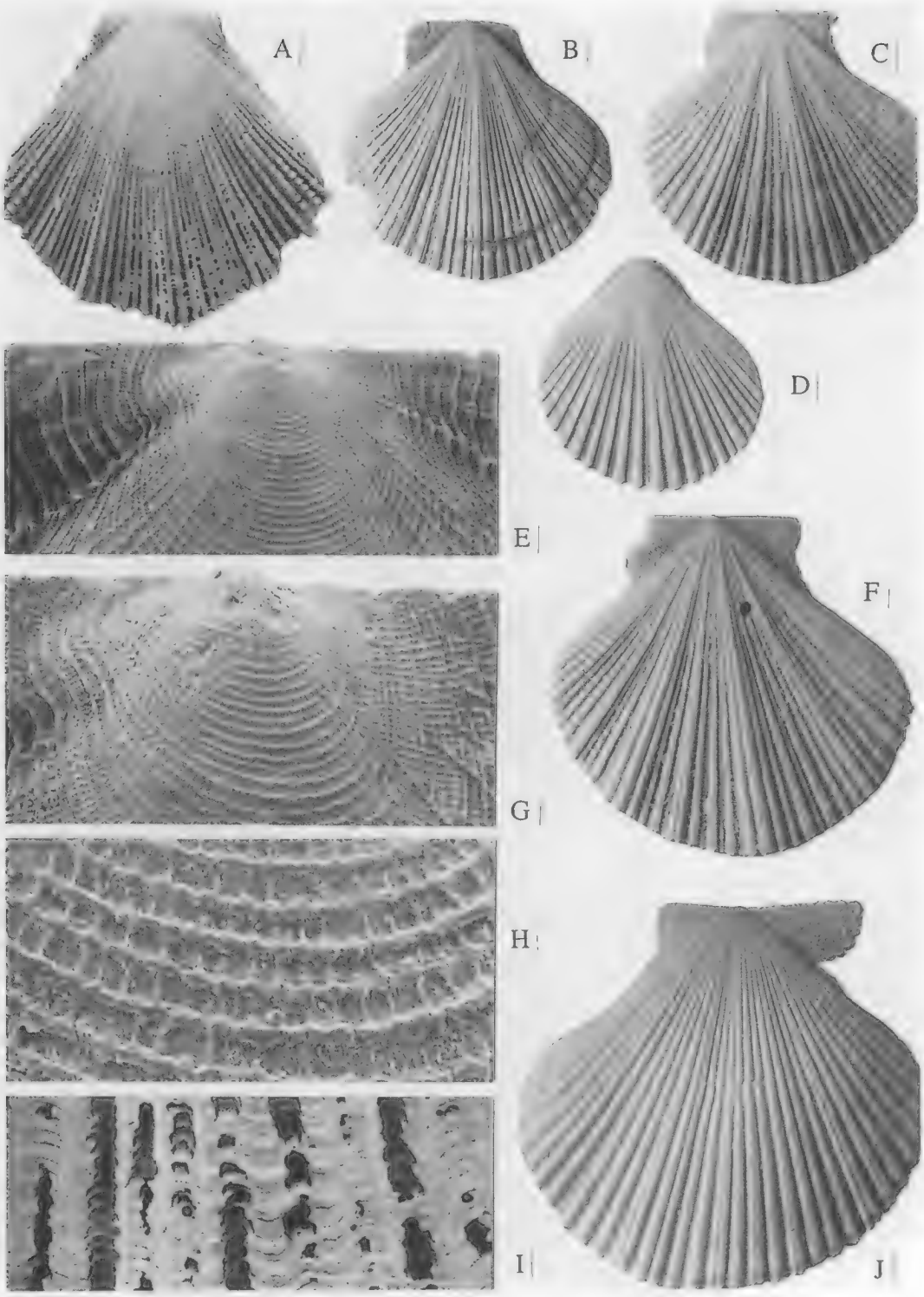
Type material. As noted above under *Semipallium foulcheri*, Tenison Woods' (1865) four pectinids all require neotypes. Tenison Woods (1865) remarked of *Pecten incertus* that 'it is said to be common at the Murray beds and at Hamilton'; he was adamant that 'I have never found the fossil in the Mount Gambier rocks'. The published lithograph does not clearly depict any particular species, and Tenison Woods commented 'the drawing represents a somewhat abnormal form', but from his statement of the localities it appears likely that he intended to name the relatively large, common *Mesopeplum* species from the Balcombian Morgan Limestone on the Murray River and the Muddy Creek Formation at Muddy Creek, near Hamilton, Victoria. Well preserved specimens are much more common in Morgan Limestone than in Muddy Creek Formation; the few specimens which we have seen from are abraded and have many epibionts attached to the exterior. We therefore designate as neotype of *Pecten incertus* Tenison Woods, 1865, NMV P300904 (Fig. 56E), a RV from Morgan Limestone (Balcombian), PL3214, cliff on left bank Murray River 3.5 km southeast of Cadell, South Australia, grid ref. Cadell 883311, coll. A. G. Beu & T. A. Darragh, 29.ix.1993; with four other valves, NMV P302097–302100.

Other material examined. **Batesfordian:** FYANSFORD FORMATION: PL3039, Ad12, Curlewis (1 specimen); Curlewis (1 specimen); WUK WUK MARL: PL3054, Skinners (9 specimens). **Balcombian:** CADELL MARL: PL3084, Cadell Marl lens (16 specimens); FYANSFORD FORMATION: PL3072, Orphanage Hill, Fyansford (1 specimen); PL3077, Altona Bay coal shaft (3 specimens); Balcombe Bay, Mornington (3 specimens); Moorabool Valley (4 specimens); GELLIBRAND FORMATION: Gellibrand River (1 specimen); AMS C109910, SE end Gibson's Beach, SE of Port Campbell (2 specimens); MORGAN LIMESTONE: PL3197, Greenways Landing (10 specimens); PL3214, 3.5 km S of Cadell (5 further specimens, ie., 10 including material listed under 'Type material'); PL3217, Murray cliffs, 'Yarra View' (31 specimens); PL6668, Overland Corner (3 specimens); upper part of lower beds, Murray cliffs at Morgan (41 specimens); lower bed, Murray cliffs at Morgan (10 specimens); River Murray cliffs 6.4 km below Morgan (1 specimen); Tate's bed 9, Morgan (13 specimens); Tate's bed 9, 6.4 km below Morgan (4 specimens); AMS F1729, Murray River cliffs, 'received from Prof. R. Tate', identified as *P. polymorphoides* (2 specimens); AMS F49414, Murray River, 320 km from Adelaide (1 specimen); AMS F5890, cliff 57, Parish of Stuart, Murray River (1 specimen); MUDDY CREEK FORMATION: PL3082, Clifton Bank, Muddy Creek (16 specimens); Muddy Creek, near Hamilton (15 specimens); AMS, between Clifton Bank and McDonald's Bank, Muddy Creek (1 specimen); GIPPSLAND LIMESTONE (Balcombian): railway cutting, Newmerella (1 specimen). **Bairnsdalian:** FYANSFORD FORMATION: PL3100, Murgheboluc 4A (2 specimens).

Occurrence and time range. Batesfordian, few specimens; Balcombian and Bairnsdalian; moderately common at some localities in Morgan Limestone, Murray Basin, and in Muddy Creek Formation, Otway Basin. Batesfordian specimens are slightly less inflated than typical Balcombian specimens, but are much larger than *M. minimum* and have much more strongly discrepant valve inflation, and certainly are much more nearly similar to *M. incertum* than to the more common Batesfordian species, *M. minimum*. The only other material we have seen is from Fyansford Formation around Melbourne and Geelong, from both Balcombian and Bairnsdalian parts of the formation, and from Balcombian units in Gippsland. In limestone lithologies of Bairnsdalian age, *M. incertum* is replaced by *M. subconvexum*.

Remarks. *Mesopeplum incertum* is moderately large, reaching 45 mm in height, and is exceeded in size only by *M. contrainflatum* and *M. meringae*, among Australian species. *M. incertum* is the most similar of all the fossil species to the living type species, *M. fenestratum*, in size, shape and sculpture, and seems likely to be closely related phylogenetically to that species. The radial costae are prominent and narrow on most specimens, although their prominence is variable and, on some specimens, low, obscure costae on plical crests give the shell a much smoother appearance than the usual strongly costate form. Growth ledges are more common in this species and in *M. minimum* than in any other Australian *Mesopeplum* species, and many large valves have 3 to 5 ledges; those on LVs are more prominent than on RVs in most specimens of *M. incertum*. The ctenolial teeth are set on a very prominent, smooth ridge extending down the edge of the byssal fasciole, well elevated above the disc surface.

The closest species to *M. incertum* is the New Zealand Miocene species *M. burnetti* (Zittel). This is the most common and widespread New Zealand species of *Mesopeplum*, recorded from rocks of Waitakian (basal Miocene) to Kapitean (latest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Miocene) age, with one record from Opoitian (Early Pliocene) rocks (Beu 1995: 52). Although closely similar to *M. incertum* in overall appearance because of its similarly coarse plicae and radial costae, *M. burnetti* differs from *M. incertum* in its larger size (commonly reaching *c.* 60 mm long), its longer and wider shape (ie., with a wider umbonal angle), its consistently higher, more prominent and more widely spaced radial costae, and its slightly lesser inflation. The byssal notch and fasciole remained functional in large adults of *M. burnetti*, as in *M. incertum*. These relatively minor differences suggest that there is a close phylogenetic relationship between these two species; ie., there was at least some trans-Tasman larval exchange at this time. As *M. burnetti* is recorded from rocks at least as early as basal Miocene, and *M. incertum* is recorded first in late Early Miocene (Batesfordian) rocks, it seems feasible that *M. burnetti* was the immediate ancestor of *M. incertum*.

Tate (1886: 113) identified this species with *Pecten polymorphoides* Zittel, from 'Waikato South Head', New Zealand, presumably from an Oligocene limestone of Te Kuiti Group. Zittel's (1864: pl. 11, fig. 3) drawing shows a very small shell with 6 smooth plicae, resembling *M. syagrus* Marwick (1924: pl. 5, fig. 7) in most characters, although much smaller. AGB examined the holotype in Naturhistorisches Museum Wien (No. 1959/335/42) during June 1998, and found it to be a poorly preserved specimen (with much of the outer shell material missing), of small size (H 16.4, L 14.5 mm), apparently conspecific with *M. syagrus*. Tate's identification with the New Zealand species was based on comparison with specimens from New Zealand sent by James Hector (as noted in the introduction), but Hector's identification of the New Zealand species with *M. polymorphoides* (Zittel) would also be considered incorrect today; his material almost certainly belonged in *M. burnetti* (Zittel). There is no doubt that Tate's identification was incorrect.

Mesopeplum subconvexum (Tate, 1887)

Fig. 57A–J

Pecten subconvexus Tate, 1887d: 185, pl. 18, fig. 2; Tate, 1899: 270.

Chlamys (Mesopeplum) incerta; Ludbrook, 1955: 32, pl. 5, figs 8, 9 (not *Pecten incertus* Tenison Woods, 1865).

Description. Small, reaching *c.* 33 mm high and 35 mm wide, but most specimens not exceeding 25 mm wide; weakly inflated, RV markedly less inflated than in *M. incertum*, LV very weakly inflated to almost flat; moderately to strongly prosocline; umbonal angle *c.* 100–105°; plicae weak, wide, low and particularly weak on RV, narrower and more prominent on LV, median one on LV the most prominent; many specimens with a few weak growth ledges. Exterior sculpture of *c.* 25–35 prominent, moderately to very wide radial costae with sharply defined edges, irregularly subdividing and intercalating to a small degree, quite constant in number on many specimens, on most specimens with relatively deep interspaces each the same width as one costa, on unabraded specimens bearing prominent low, flexuous, commarginal ridges with convex curve towards venter, but lamellae abraded off many specimens, including holotype. Auricles, byssal notch and ctenolium as in *M. incertum*, except that byssal notch is slightly narrower and ctenolial ridge is lower than in *M. incertum*. Interior weakly corrugated, but with short, very prominent rib carinae around ventral margin. Hinge as in *M. incertum*, except that resilial teeth diverge more strongly than in that species.

Dimensions.

Holotype of *Pecten subconvexus* SAM T958	H 32.3	L 31.2	LV
NMV P302129, Grange Burn	23.1	22.4	LV
NMV P302189, PL3132, Minhamite	28.3	28.9	LV
NMV P300889, Dry Creek Sands	25.0	26.5	LV
NMV P300130 Bairnsdale Limestone	32.2	34.4	LV
NMV P300131, as above	30.6	32.1	RV

Fig. 57. Mesopeplum subconvexum (Tate). A, E, G–I, SEMs of small LV, P300282, lower Dry Creek Sands (Bairnsdalian), 82–84 m in bore 323, Waterloo Corner, South Australia: A, whole shell, enlarged, × 5.5 (H 8.6 mm); sculpture of preradial dissoconch (E × 24, G × 50, H × 180); I, disc sculpture near ventral margin, × 40, showing false surface produced by commarginal lamellae uniting above true valve surface. B, abraded LV, P302189, Goodwood Formation (Mitchellian–Cheltenhamian?), Spring Creek, Minhamite, western Victoria, enlarged, × 2. C, LV, P302130, enlarged, × 1.25, and J, RV, P302131, enlarged, × 2, both from Bairnsdale Limestone (Bairnsdalian), E side of Nowa Nowa Arm, Lake Tyers, Gippsland, Victoria. D, holotype of *Pecten subconvexus* Tate, SAM T958, a severely abraded LV, 'Miocene, Muddy Creek', ie., reworked into Grange Burn Formation (Kalimnan) from an older unit, Muddy Creek, near Hamilton, western Victoria; at natural size. F, LV, P300889, lower Dry Creek Sands (Bairnsdalian), Angus House bore, Salisbury, South Australia, enlarged, × 2.

Type material. Holotype of *Pecten subconvexus* Tate, SAM T958, labelled 'Miocene, Muddy Creek', ie., Grange Burn Formation, Kalimnan (Pliocene), but reworked from an older unit, about Bairnsdalian–Cheltenhamian in age; from J. Dennant Collection.

Other material examined. **Bairnsdalian:** BAIRNSDALE LIMESTONE: PL3105, Pleasant Creek quarry (20 specimens); PL3107, McCraes Quarry (44 specimens); PL3256, Myrtle Point (10 specimens); PL3257, Schaeche's Track (26 specimens); PL3258, Dooley St pit (9 specimens); PL3174, Nelson Bros. quarry (94 specimens); PL3175, Cameron Arm No. 2 track (112 specimens); Driers, Mitchell River (23 specimens); Pound Creek Reserve, Bairnsdale (9 specimens); Boggy Creek, Bairnsdale (8 specimens); Nicholson River (4 specimens); cliff on W bank Tambo River, NW corner allot. 89, Parish of Bumberrah (3 specimens); cliff on Tambo River 3.2 km N of Swan Reach (2 specimens); Princes Highway cutting at Toorloo Arm, Lake Tyers (51 specimens); Hospital Creek, Gippsland (7 specimens); drainage excavation N side railway line, 0.8 km W of Simpsons Creek, *c.* 16 km W of Orbost (3 specimens); AMS F744, Bairnsdale (2 specimens); PORT CAMPBELL LIMESTONE: top of cliffs, Bay of Islands, Peterborough (4 specimens); near top of cliff, W end Bay of Islands, Peterborough (3 specimens); 3 m from cliff top, beneath red clay, Peterborough (3 specimens); cliff E end Crofts Bay, W of Peterborough (3 specimens); past cave, 5 m above sea-level, nr Hopkins River, Warrnambool (1 specimen); WAM 67.1090–1092, Bay of Islands, 6.4 km W of Peterborough (3 specimens); WUK WUK MARL: PL3108, Driers (19 specimens); BOOKPURNONG FORMATION: PL3133, Wookool Bend, near Loxton (6 specimens); DRY CREEK SANDS: PL3299, Abattoirs Bore (4 specimens); PL3596, Angas Home bore (13 specimens); PL3598, Waterloo Corner bore (5 specimens). **Bairnsdalian–Cheltenhamian:** GRANGE BURN FORMATION [remanié, in Kalimnan]: PL3137, Forsyth's Bank (8 specimens); PL3139, McDonald's Bank (2 specimens); GOODWOOD FORMATION: PL3132, Spring Creek, Minhamite (20 specimens).

Occurrence and time range. Apparently limited to Bairnsdalian, although possibly as young as Cheltenhamian in Goodwood Formation, Otway Basin. Abundant in Bairnsdale Limestone throughout the Gippsland Basin, and fewer specimens in several other Bairnsdalian units. *M. subconvexum* is likely to be of high biostratigraphic utility.

Remarks. Tate's (1887d: 185) holotype of *Pecten subconvexus* is a severely abraded, weakly inflated LV with relatively few, coarse, wide radial costae and very low, obscure plicae, from the 'upper beds' (Grange Burn Formation, Kalimnan) at Muddy Creek, near Hamilton, Victoria. Like many abraded specimens from Grange Burn Formation, it clearly has been reworked from an older unit into the younger formation, and Tate (1899: 270) acknowledged this possibility by stating 'Miocene—Muddy Creek, but possibly derived from the Eocene'. However, no specimens of a *Mesopeplum* species resembling the holotype of *M. subconvexum* have been collected from the underlying Muddy Creek Formation, which seems to contain only *M. incertum*. NMV collections contain 7 other specimens from Grange Burn Formation, and these are less abraded than the holotype and are more useful for comparison. This material of *M. subconvexum* seems to have been reworked from an unknown unit younger than Muddy Creek Formation but older than Grange Burn Formation.

An important clue to the identity of *M. subconvexum* is a collection from Goodwood Formation at Spring Creek, Minhamite, in western Victoria, of about Bairnsdalian–Cheltenhamian age, to judge from the associated fauna, which includes common *Mimachlamys asperrima*. From here, Julian Hollis collected 20 valves of *M. subconvexum*, including some specimens with relatively few, coarse radial costae, as in the holotype. However, this is an uncommon form in the population; most specimens have more numerous, finer radial costae. All specimens are strongly prosocline in shape, with a very weakly inflated to almost flat LV with 5–6 narrow, weak plicae, and a moderately weakly inflated RV with 5 low, wide, weakly defined plicae, all bearing numerous simple, rather coarse radial costae of almost square section, the entire exterior covered with far-set commarginal lamellae. These specimens agree in all details with a common *Mesopeplum* species in Bairnsdale Limestone throughout the Gippsland Basin, with uncommon specimens in Port Campbell Limestone, Otway Basin, with a few specimens from Bookpurnong Formation in the Murray Basin, and with moderately common specimens [identified by Ludbrook (1955: 32) as *M. incertum*] from Dry Creek Sands in St Vincent Basin. A specimen from Dry Creek Sands was studied by SEM, and demonstrated that this species has markedly coarser LV preradial dissoconch sculpture than any other Australian species we have examined (Fig. 57E, G, H). We can see no differences of taxonomic significance between the collections we include here from different localities, and we identify this widespread species as *M. subconvexum* (Tate). Specimens from Bairnsdale Limestone reach a slightly larger maximum size than others we have seen (up to *c.* 33 mm high) but are otherwise identical, and the greater maximum size in Bairnsdale Limestone is likely to be due simply to the huge sample available. *M. subconvexum* retains a deep, narrow byssal notch and functional ctenolium in adults, the ctenolium being situated on a raised, smooth, cord alongside the byssal fasciole, and its auricles are almost identical to those of *M. incertum*. It is

therefore similar to *M. incertum* in many characters, differing in the lower inflation, particularly of the almost flat LV, in the lower and less obvious plicae, and in the more coarsely sculptured LV preradial dissoconch than in *M. incertum*.

Mesopeplum*(?) *contrainflatum sp. nov.

Fig. 58A–D

Description. Moderately large for genus (to 52 mm high and 55 mm long), markedly longer than high, strongly prosocline, posterodorsal margin up to 1.5 times length of anterodorsal margin; LV moderately to very strongly inflated and RV weakly to very weakly inflated; umbonal angle *c*. 110°. Plicae very low and weak, *c*. 3–5 discernible over proximal 15 mm of LV, fading out gradually below that, scarcely visible at all on RV. Radial sculpture of 20–22 low, square-edged primary radial costae over proximal 15–25 mm of disc, gradually widening and subdividing irregularly more distally to form many irregular, low, wide, indistinct costae, on some specimens grouped regularly into three narrow costellae over at least part of disc, in others arranged as roughly alternating wider and narrower costae over at least part of disc, random in others, tending to remain higher and less frequently subdivided on RV than on LV; low, narrow and widely spaced on auricles, very weak on posterior auricle of some specimens. Whole surface crossed by many, thin, well elevated, relatively widely spaced commarginal lamellae, closely spaced and forming dominant sculpture on auricles. RV anterior auricle (complete on only one specimen) moderately long, with wide, shallow, functional byssal notch, ctenolial teeth raised on a very narrow ridge and upper margin of notch edged with small, sharp points at ends of radial costae of auricle as in *M. meringae*. LV anterior auricle moderately long, triangular, with anterior margin inclined strongly anteriorly. Posterior auricles small, short, with weakly concave posterior margins. Hinge visible in only one RV; with very low dorsal teeth but moderately prominent resilial teeth beside dorsal half of resilium. Interior almost smooth, with very weak, rudimentary rib carinae around outermost ventral margin.

Dimensions.

Holotype NMV P302093	H 52.2	L 54.8	LV
Paratype, NMV P302092	48.4	48.3	RV
Paratype, AGSO CPC F888	51.7	53.7	2 valves

Type material. Holotype, NMV P302093, PL3118, lower Jemmys Point Formation (Cheltenhamian), floor and sides of disused tramway cutting, north of Scrivenors Road, west side of Mississippi Creek, near Lakes Entrance, Gippsland, Victoria, grid ref. Colquhoun 836116, coll. F. A. Cudmore, 1936, 1939; one paratype, NMV P302092, RV, all data as above, coll. A. G. Beu & T. A. Darragh, 19.xi.1993; one paratype, NMV P302094, an incomplete RV, all data as for holotype; one paratype, an articulated pair with incomplete auricles, AGSO CPC F888, from 'Tram track, Mississippi Creek, Lakes Entrance, Victoria', ie., from the type locality, but accompanied by one valve of *M. divergens* sp. nov., which is probably mislocalised as we have seen no other material of *M. divergens* from the tramway cutting at Mississippi Creek, and, indeed, its apparent successor, *M. meringae* (Tate), is known by a few specimens from the Mississippi Creek cutting.

Other material examined. Type locality only (7 specimens).

Occurrence and time range. Cheltenhamian; known only from the type locality, occurring with *Mesopeplum meringae* (Tate) and *Mimachlamys asperrima*.

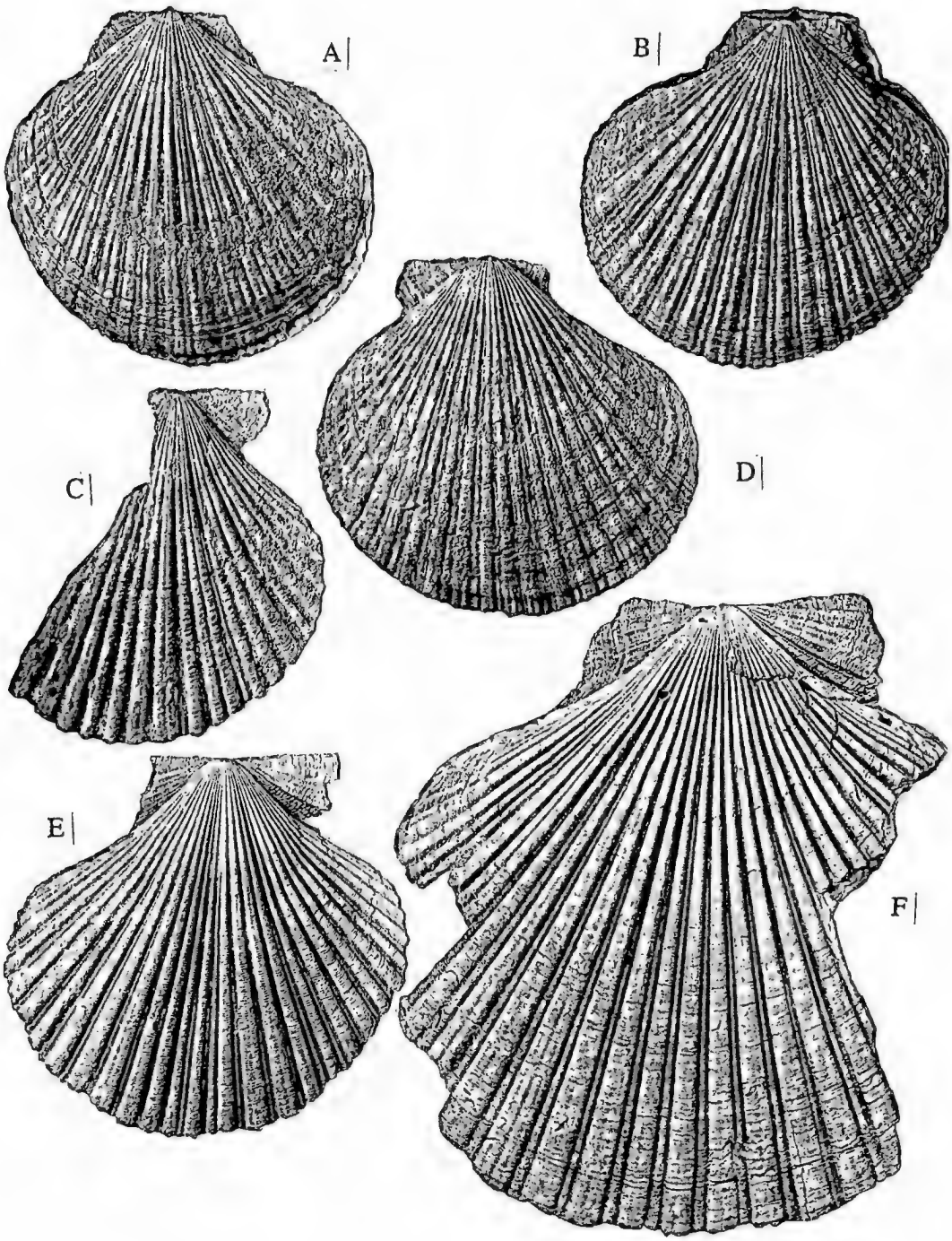
Remarks. This species is much the most distinctive of all those we include here in *Mesopeplum*, and the unusual, crude radial sculpture, the very weak plicae, the very weak internal rib carinae and, in particular, having the opposite valve the more inflated to that of all other *Mesopeplum* species we are aware of in Australia and New Zealand, suggest that it possibly belongs in a genus distinct from *Mesopeplum*. However, we have seen relatively little material, the one outcrop it occurs at being now severely overgrown, and almost all material has the exterior coated with pedogenic carbonates, so we know few of the phylogenetically useful characters of *M. contrainflatum*. At present, we retain it in *Mesopeplum*, hoping that more, better material will further clarify the identity of the species. It is unusual for a pectinid species to be limited to a single outcrop that seems lithologically indistinguishable from the many others nearby in Gippsland, and the species might well turn out to have a short stratigraphic range.

Etymology. The specific name (Latin, '*contra*', against or opposite +'*inflatus*', inflated) refers to this species having the opposite relative valve inflation to that of all other species included in the genus.

Mesopeplum divergens sp. nov.

Fig. 59A–I

Description. Moderate-sized (to *c*. 40 mm high and 43 mm long), acline to very slightly prosocline, with moderately wide umbonal angle (*c*. 100–105°), length significantly greater than height; RV weakly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inflated for genus, LV almost flat, particularly over proximal quarter to third of disc. Juvenile specimens not seen, LV preradial dissoconch studied by SEM on slightly abraded, half-grown specimen, clearly with prominent, narrow, closely spaced antimarginal ridgelets, but commarginal ridges much less obvious and less prominent than on other species of genus. Plicae low and not greatly obvious, 5 present on almost all specimens, wide on RV with interspaces each about a quarter width of one plica, indistinct near anterior and posterior ends of disc, central interplical depression the most obvious fold on most RVs; correspondingly low and narrow on LV, central narrow plica the most obvious fold on most LVs. Radial sculpture of relatively few, coarse and irregularly subdivided, well elevated costae of rectangular section, varying from *c.* 3 to 7 on each plica on RV, with 1 to 3 narrower costae in each plical interspace, radial interspaces each as wide as one costa to very much narrower than one costa, with very low, narrow, secondary costellae intercalated in centre of some interspaces on some specimens; 2–3 prominent, weakly subdivided costae per plica on LV, with 3–5 costae of highly varied width and prominence in each interplical space, and with very low, narrow secondary and tertiary costellae intercalated in many intercostal spaces on most specimens; costae near anterior and posterior ends on both valves conspicuously curved outwards parallel to concave anterodorsal and posterodorsal margins of valves. Entire surface sculptured with obvious, far-set commarginal lamellae, on most specimens free and separate over much or all of RV but united to form secondary surface over much of LV, particularly on costal and plical crests and on costae at anterior and posterior ends of valve, lamellae raised into low, wide, triangular, ventrally directed scales on costal crests on many LVs, particularly on costae on anterior and posterior ends of valves and on anterior auricle. RV anterior auricle triangular, with strongly pointed anterior extremity, deep, narrow byssal notch, narrow, depressed byssal fasciole, and ctenolium with 4 functional teeth in adults, main face above byssal fasciole sculptured with 5–6 prominent, narrow, widely spaced radial costae, commarginal lamellae particularly prominent over dorsal half of many specimens, strongly serrating dorsal margin. LV anterior auricle large, triangular, with weakly sinuous anterior margin inclined strongly towards anterior, sculptured with 6–8 prominent, narrow radial costae crossed by extremely prominent, widely spaced, commarginal lamellae raised into prominent triangular scales on each radial costa. Posterior auricles relatively large, triangular, with sinuous posterior margin; weakly sculptured on RV, with 2–3 low radial costae; more prominently sculptured on LV, with 4–6 narrow radial costae and prominent commarginal lamellae, costal scales less prominent than on anterior auricle in most specimens. Interior weakly corrugated, corrugations developing into prominent, sharp carinae around interior of ventral margin. Hinge with long, narrow dorsal teeth and one pair of short, narrow, prominent resilial teeth above dorsal half of resilifer in RV, sockets for resilial teeth prominent in LV.

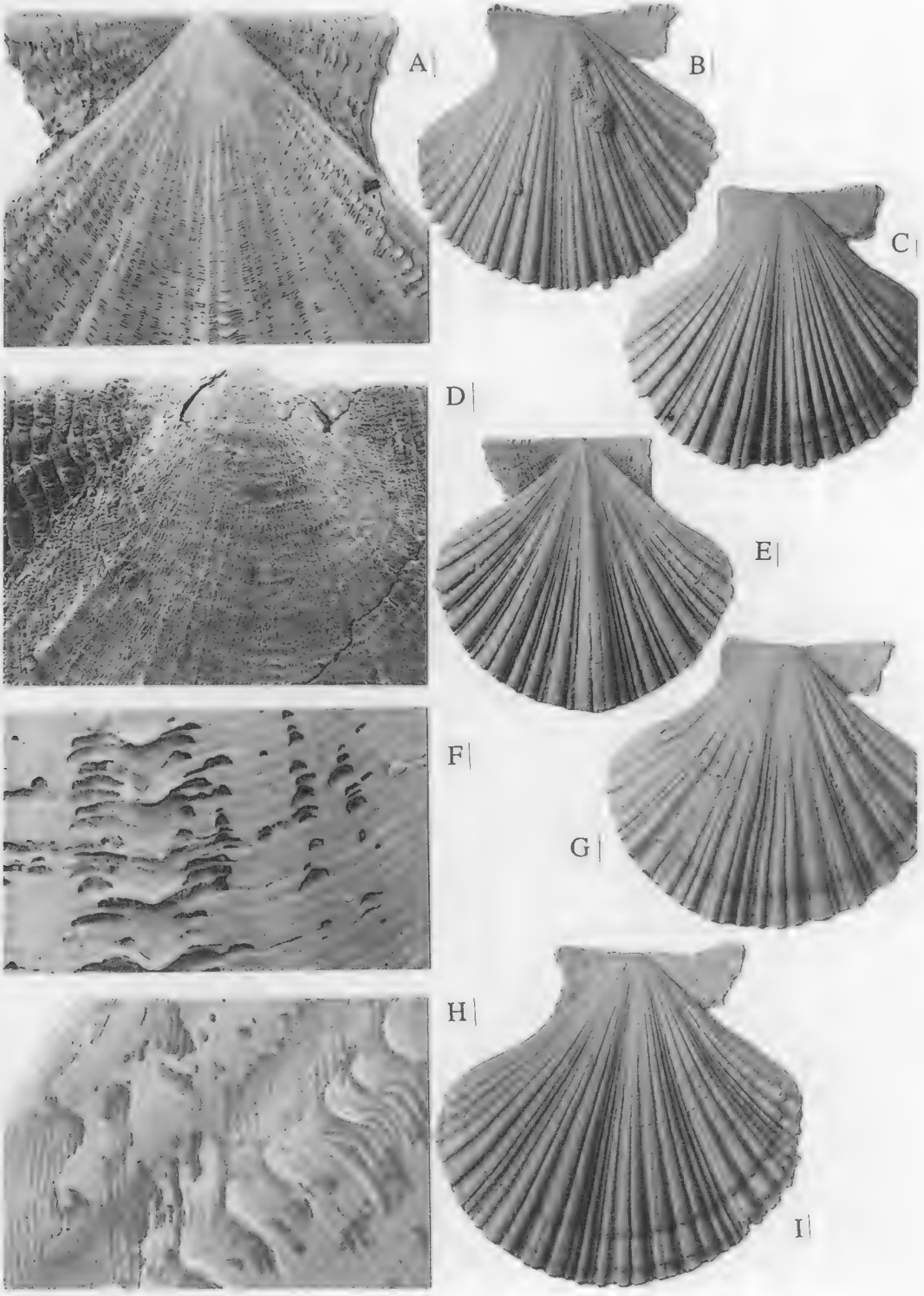
Dimensions.

Holotype, NMV P302119	H 33.5	L 36.7	RV
Paratype			
NMV P302121, Swan Reach	40.8	43.2	RV
NMV P302122, Swan Reach	32.7	36.6	LV
NMV P302123, Beaumaris	34.1	38.3	RV
NMV P302118, Lake Tyers	32.7	34.0	RV

Type material. Holotype, NMV P302119, Tambo River Formation (Mitchellian), PL3110, cutting on Swan Reach–Metung Road, left bank Tambo River, *c.* 200 m south of Princes Highway, Swan Reach, Gippsland, Victoria, coll. F. A. Cudmore, 1936–1940; three paratypes, NMV P302120–302122, 2 RVs and 1 LV, all data as for holotype; one paratype, NMV P302118, Tambo River Formation (Mitchellian), PL3267, *Serripecten carteri* locality, Lake Tyers, coll. A. G. Beu & T. A. Darragh, 21.xi.1993; one paratype, NMV P302123, Black Rock Sandstone (Cheltenhamian), above nodule bed, Beaumaris, near Melbourne, Victoria, coll. F. A. Cudmore, 1903.

Other material examined. **Mitchellian:** TAMBO RIVER FORMATION: PL3110, Swan Reach cutting (190 specimens); PL3267, Reedy Arm peninsula, Lake Tyers (39 specimens). **Cheltenhamian:** BLACK ROCK SANDSTONE: Beaumaris (17 specimens); above nodule bed, Beaumaris (22 specimens).

Fig. 58. A–D, *Mesopeplum*(?) *contrainflatum* sp. nov., Jemmy's Point Formation (Cheltenhamian), tramway cutting, Mississippi Creek, near lakes Entrance, Gippsland, Victoria; at natural size: A, LV, and B, RV of articulated pair, paratype, AGSO CPC F888; D, LV, holotype, P302093; C, incomplete RV referred to this species, P302094. E, F, *Mesopeplum meringae* (Tate), Jemmy's Point Formation, Lakes Entrance area, Gippsland, Victoria; at natural size: E, unusually coarsely sculptured RV, P302111, Cheltenhamian, tramway cutting, Mississippi Creek, near Lakes Entrance; F, large, unusually weakly inflated RV, P302102, PL3269, nodule bed (Cheltenhamian), E side of Trident Arm, Lake Tyers.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Occurrence and time range. Mitchellian and Cheltenhamian. Common at both Mitchellian localities in the Gippsland Basin. Uncommon and a little abraded, with much of the microsculpture polished off, in Black Rock Sandstone at Beaumaris (Cheltenhamian). We have seen it from only these three localities. *M. divergens* has a narrow time range, but is absent from the numerous Cheltenhamian outcrops of normal silty sandstone (lower Jemmys Point Formation) throughout the Gippsland Basin, and so appears to be limited to lithologies with a low sedimentation rate, such as greensand.

Remarks. *Mesopeplum divergens* sp. nov. is a very distinctive species, because of its wide shape, its flat LV, its coarse radial sculpture, its weak plicae with one or a few narrow plicae near the centre of the valve more prominent on the LV than any of the others on either valve of most specimens, its very obvious secondary shell surface formed by the commarginal lamellae on most LVs, and the unique, low triangular scales on the major costal crests, present on the costae on the crests of all plicae on some specimens, and at least on the ends of the LV and on the anterior auricle on almost all specimens. The specimens from Beaumaris have the microsculpture abraded off, including the triangular scales, but agree with the Gippsland material in all other details, such as the shape of the RV posterior auricle, and are certainly conspecific. The shape of the auricles is very similar to that of the younger species *M. meringae*, and it appears likely that *M. divergens* was either ancestral to *M. meringae* or, more probably, they are sister species. *M. meringae* reaches a very much larger size than *M. divergens* (up to 100 mm high), has proportionally much weaker sculpture with much more numerous radial costae but more normal plicae of relatively high amplitude on most specimens, and lacks the unique triangular costal scales of *M. divergens*.

Etymology. The specific name (Modern Latin, '*divergens*', diverging) refers to the unusually obviously curved, diverging radial costae near the anterior and posterior ends of the disc in this species.

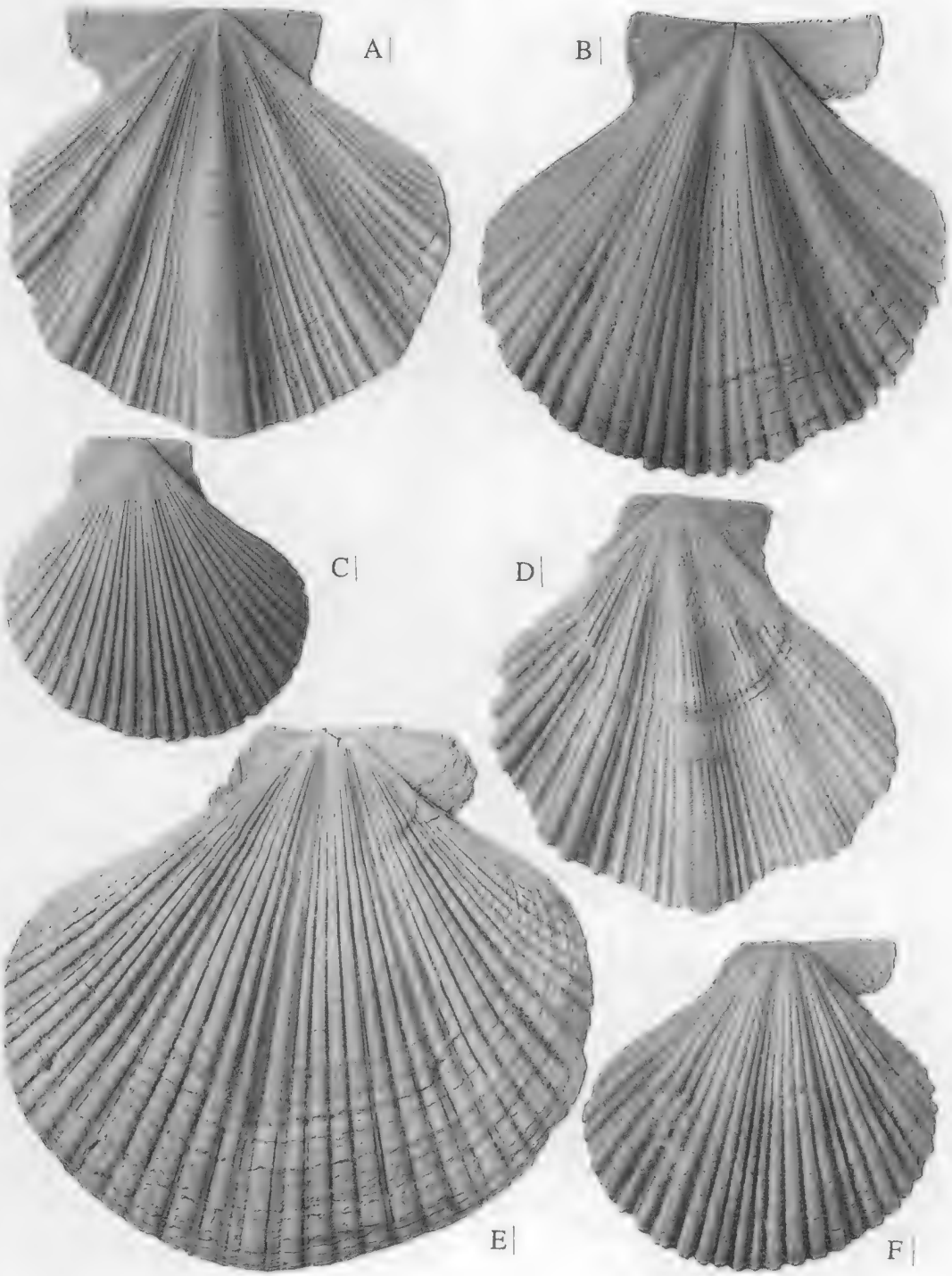
Mesopeplum meringae (Tate, 1899)

Figs 58E, F, 60A–E

Pecten meringae Tate, 1899: 271.

Description. Very large for genus, to *c.* 100 mm high; both valves moderately inflated, RV a little more inflated than LV; weakly to moderately strongly prosocline; umbonal angle moderately wide, *c.* 105–110°. Plicae moderately prominent, persistent across disc of most moderately large specimens, becoming weaker over outer quarter to third of large specimens, wider and more closely spaced on RV, narrower, more prominent and more widely spaced on LV; 5 plicae on most specimens; few, weak growth ledges observed. Exterior sculpture of *c.* 26–40 well raised radial costae, few, coarse and undivided on a few specimens, subdividing and intercalating across disc to increase in number during growth in many specimens; almost smooth-surfaced in some specimens, but on unabraded specimens bearing obvious, low, narrow, widely spaced commarginal ridges, which form more prominent lamellae across floors of radial interspaces. RV anterior auricle moderately long, with weakly depressed byssal fasciole, narrow byssal notch, and ctenolium situated on a low, smooth ridge; anterior outline almost evenly curved to weakly polygonal; main face above byssal fasciole sculptured with 5–7 narrow, widely spaced radial costae, protruding slightly to form weak angulations of anterior auricle outline; LV anterior auricle moderately long, anterior margin deeply sinuous, inclined strongly towards anterior; posterior auricles moderately long for genus, with sinuous posterior margin, inclined towards posterior at base and then almost vertical or inclined slightly towards anterior. Interior moderately to strongly corrugated, with moderately long, prominent rib carinae around ventral margin. Hinge very weak, with long, narrow dorsal teeth, faint resilial teeth distinguishable in some specimens.

Fig. 59. Mesopeplum divergens sp. nov., all from Victoria. A, D, F, H, SEMs of small paratype LV, P300413, Tambo River Formation (Mitchellian), PL3110, cutting on Swan Reach–Metung Road, 200 m S of Princes Highway, Swan Reach, Gippsland; enlargements of umbo and auricles (A × 4; H 21.2 mm, hinge length 14.1 mm), of early sculpture on umbonal area (D × 35), and of costae on disc, bearing triangular scales (F, H, both × 20). B, paratype RV, P302118, PL3267, Tambo River Formation (Mitchellian), Reedy Arm peninsula, Nowa Nowa Arm, Lake Tyers, Gippsland, enlarged, × 1.25. C, E, I, all data as for Fig. 59A, D, F, H, all enlarged, × 1.25: C, holotype RV, P302119; E, paratype LV, P302122; I, paratype, RV, P302121; G, paratype RV, P302123, Black Rock Sandstone (Cheltenhamian), above nodule bed, Beaumaris, near Melbourne; × 1.25.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Dimensions.

Lectotype of *Pecten* meringae Tate SAM T947A	H 63.6	L 66.0	LV
Paralectotype, SAM T947B	41.1	40.4	LV
NMV P302102, large RV, PL3269 Trident Arm	93.8	80.6	RV
NMV P302111, tramway cutting Mississippi Creek	55.0	58.6	RV
NMV P302089, Godsall's Pt Lakes Entrance	54.0	55.1	RV

Type material. An unusual situation exists with the type(?) material of *Mesopeplum meringae* as, although two LVs of the common, large species in Jemmys Point Formation that we have assumed is *M. meringae* are present and registered in the Tate type collection, SAM, they are not registered as types, and they bear no original Tate label to identify them as types. It seems likely that this has arisen because Tate (1899) did not illustrate the species, so whoever registered the material was unable to confirm from an illustration that one of these two specimens was among the type material, as can be done with almost all of Tate's other pectinids. No other specimens of *M. meringae* are known that belonged to Professor Ralph Tate in any collection we have consulted, and so these specimens are assumed to be his syntypes of *Pecten meringae*. These specimens, SAM T947A, B (Fig. 60A, D), are labelled 'Miocene, Gippsland', and appear to have normal Jemmys Point Formation preservation. We here designate the larger of these specimens, SAM T947A, as the lectotype of *Pecten meringae* Tate, 1899.

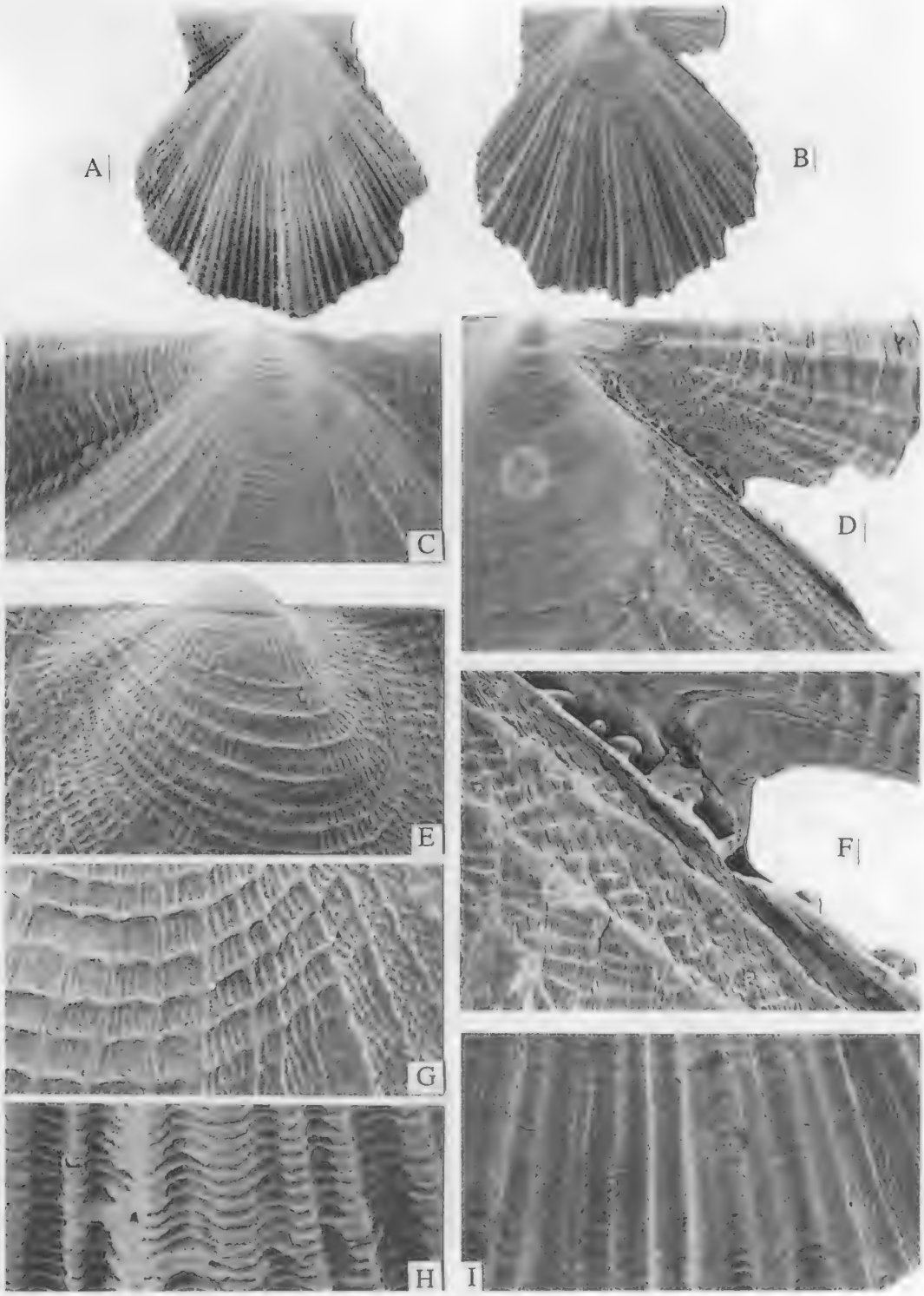
Dennant (1891) described fossil localities visited by him and Tate in Gippsland early in 1890, and mentioned a locality 'about $^3/_4$ of a mile [1.2 km] inland near the Ti Tree Swamp' where they collected '*Pecten meringae* (Tate) ms'. As is shown by his map of localities near Lakes Entrance (Denannt 1891: 67), what was then called Ti Tree Swamp is the feature now known as Meringa Creek, a short distance west of Jemmy's Point. This is still a well known locality for fossils in Jemmys Point Formation. Clearly, this locality name inspired the species name and, as it is almost certain that Tate's specimens were collected there, we designate Meringa Creek as the type locality of *Mesopeplum meringae*.

Other material examined. **Mitchellian?:** TAMBO RIVER FORMATION?: PL3260, S of Burnt Bridge Rd (9 specimens); PL3261, 0.5 km W of Long Point (37 specimens); PL3262, 0.5 km SE of Long point (34 specimens); PL3263, 0.3 km SE of Long Point (3 specimens); PL3266, due E of Long Point (18 specimens); PL3269, Trident Arm (66 specimens). **Cheltenhamian:** JEMMYS POINT FORMATION: PL3114, Bunga Creek beds 6A, B (28 specimens); PL3115, Lake Bunga crossing (9 specimens); PL3117, Bunga Creek bed b (7 specimens); PL3118, Mississippi Creek tramway cutting (13 specimens); PL3119, Ritchies cutting (18 specimens); small quarry beside tramway upstream from Armstrong's Rd, Mississippi Creek (1 specimen); PL3116, LED No. 1 bore (33 specimens); PL3120, John St, Lakes Entrance (1 specimen); PL3122, S of Hunter Gully (22 specimens); PL3123, Ferndale Parade (43 specimens); PL3124, N side Hunter Gully (26 specimens); PL3126, Nautilus Way (6 specimens); PL3265, opposite Mill Point ramp (3 specimens); PL3270, Ironbark track (20 specimens); PL3271, Morgans Landing track (5 specimens); AMS C100032, end of Hunter's Rd, North Arm, Lakes Entrance (1 specimen); shore platform, W bank North Arm S of Hunter Gully at end of Albatross Road (3 specimens). **Kalimnan:** JEMMYS POINT FORMATION: PL3148, Kalimna Jetty (9 specimens); PL3151, Nyerimalang Estates Rd (1 specimen); PL3140, Bunga Creek bed 6b (5 specimens); PL3141, W side Bunga Creek (6 specimens); cutting E side Bunga Creek (24 specimens); PL3272, South Trident Arm track (3 specimens); PL3275, Godsells Point (24 specimens); Jemmys Point (2 specimens); right bank Toorloo Arm, 1 km N of Toorloo House, Lake Tyers (13 specimens); Meringa Creek (1 specimen); Valve Oil Well bore, Pelican Point (1 specimen). **Late Pliocene**, post-Kalimnan: CAMERON INLET FORMATION: PL1250, lot 50, Lachrana (3 specimens); N end of Nelson Drain, Flinders Island (1 specimen); AMS C132746, N Patriarch dragline drain, Warren's farm, Flinders Island (1 specimen).

Occurrence and time range. Cheltenhamian and Kalimnan, to Late Pliocene (post-Kalimnan specimens from Cameron Inlet Formation) and probably as old as late Mitchellian. Common in Jemmys Point Formation and probably uppermost Tambo River Formation (the boundary between these units is not obvious in many very low outcrops around the lake shores) throughout the Gippsland Lakes region of Victoria. Apart from this, we have seen only five specimens from the Cameron Inlet Formation of Flinders Island.

Remarks. Because it has never been illustrated previously, this is one of the least known of

Fig. 60. A–E, *Mesopeplum meringae* (Tate), Jemmy's Point Formation (Cheltenhamian–Kalimnan), Gippsland, Victoria: A, D, Tate's presumed syntypes of *Pecten meringae*, both LVs, from Meringa Creek, Lakes Entrance, Kalimnan; A, lectotype, SAM T947A (designated here) of *Pecten meringae* Tate, at natural size; D, paralectotype, SAM T947B, enlarged, × 1.5; B, RV with complete auricles, P302087, PL3274, W end of Godsall's Point, Lakes Entrance, Kalimnan; enlarged, × 1.25; C, unusually narrow, strongly prosocline LV, P302106, nodule bed (Cheltenhamian), Toorloo Arm, Lake Tyers; at natural size; E, large RV (auricles incomplete), P302089, Hunter's Point, North Arm, Lake Tyers, Kalimnan; at natural size. F, *Mesopeplum incertum/fenestratum* intermediate, RV, P302112, nodule bed (Cheltenhamian), Trident Arm, Lake Tyers, Gippsland; enlarged, × 1.25.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Australian fossil pectinids, and yet it is common and, in places, even abundant, in Jemmys Point Formation in the Gippsland Basin (Cheltenhamian and Kalimnan). *M. meringae* is easily recognised by being the largest Australian species of the genus (to *c.* 100 mm high), by its rather weakly inflated RV and very weakly inflated LV, by its low but obvious, wide RV plicae and narrow, obvious LV plicae, its radial sculpture of prominent, wide, widely spaced costae on most specimens (although the sculpture is variable, and some specimens have finer and more numerous radial costae), and the long anterior auricles, the RV auricle with a deep, triangular byssal notch and functional ctenolium in adults. A few specimens in several of our collections of *M. meringae* are noticeably less inflated than the other specimens, having a narrower umbonal angle, shorter auricles and a more markedly prosocline shape than the others. The late Alan Carter had separated these specimens, thinking they might represent a distinct species. It seems more likely, though, that these (eg., Fig. 60C) are part of the variation of *M. meringae*.

Mesopeplum fenestratum (Hedley, 1901)

Figs 60F(?), 61A–I, 62A–H

Chlamys fenestrata Hedley, 1901: 730, pl. 48, figs 17–19; Hedley, 1902: 307; Pritchard & Gatliff, 1904: 265; Hedley, 1918: M9; Iredale, 1924: 194.

Chlamys hedleyi Dautzenberg, 1901: 348 (unnecessary replacement name for *Chlamys fenestrata* Hedley, 1901, thought to be a junior secondary homonym of *Pecten fenestratus* Forbes, 1844).

Mesopeplum caroli Iredale, 1929a: 162, pl. 38, figs 6–8; Macpherson & Gabriel, 1962: 305, fig. 346A, B; Iredale & McMichael, 1962: 11; Rombouts, 1991: 61, pl. 22, fig. 4; Waller, 1991: 30, pl. 3, figs 13, 17.

Mesopeplum triggi Cotton & Godfrey, 1938: 97, fig. 83; Cotton, 1961: 101, fig. 87; Rombouts, 1991: 61, pl. 28, fig. 5.

Mesopeplum fenestratum; Garrard, 1969: 5; Lamprell & Whitehead, 1992, pl. 13, fig. 78.

Semipallium fenestratum; Coleman, 1975: 280, fig. 770.

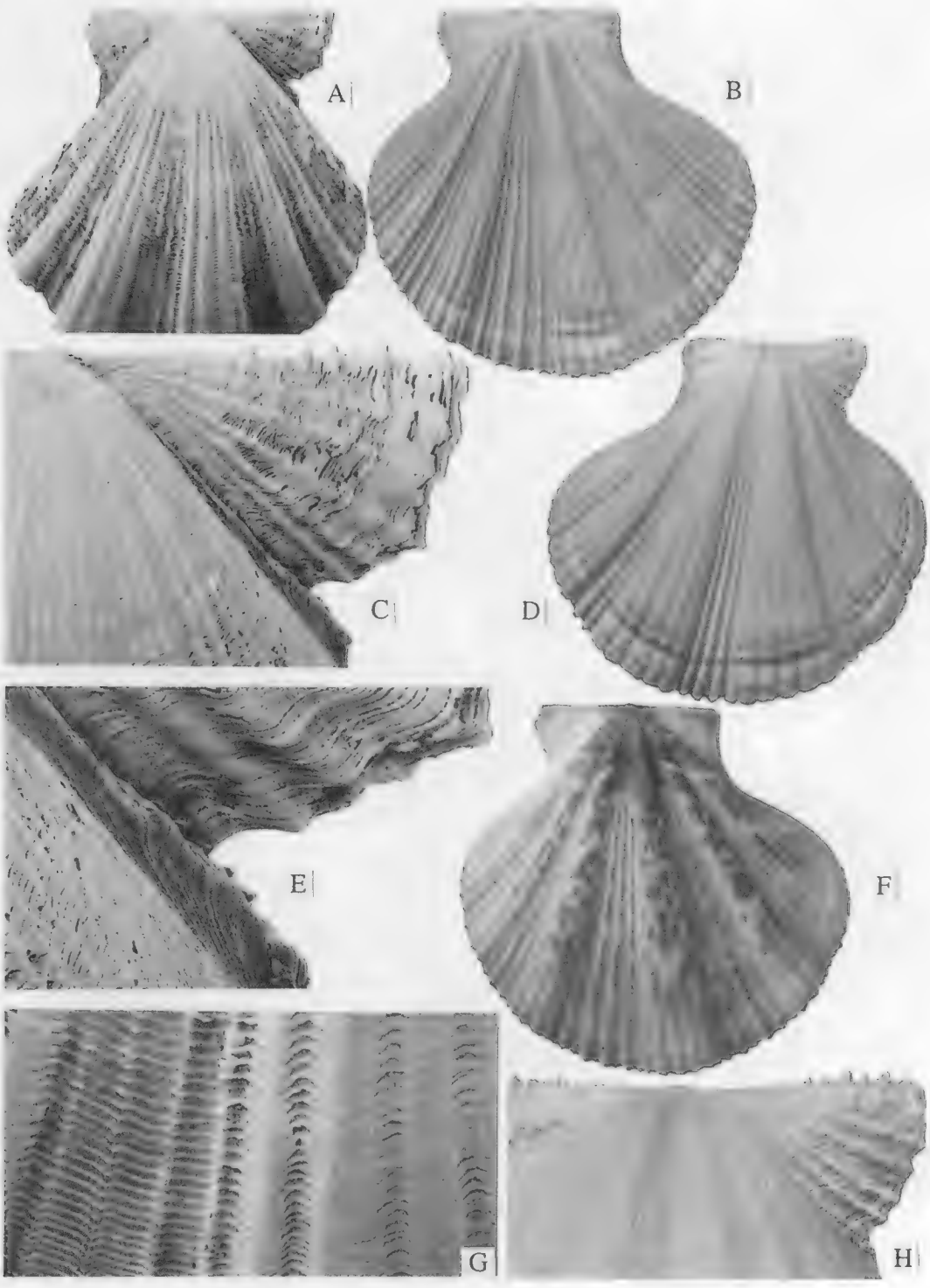
Decatopecten caroli; Wells & Bryce, 1985: 160, fig. 585.

Mesopeplum convexum; Lamprell & Whitehead, 1992, pl. 13, fig. 79 (not *M. convexum* Quoy & Gaimard, 1835, New Zealand).

Remarks. Although there is no fossil record of *M. fenestratum* itself, we do record one specimen from the Late Miocene lower part of Jemmys Point Formation in Gippsland (Fig. 60F) that has some similarities to it, and as we investigated *M. fenestratum* at some length by SEM for comparison with the fossil taxa, it is helpful to document the characters of this, the type species of *Mesopeplum*.

Although the only remnant of the byssal notch in adult *M. fenestratum* is a tiny, shallow nick in the outline of the base of the RV anterior auricle (Fig. 62D, H), small juveniles up to *c.* 5 mm high have a deep byssal notch (Fig. 61B, D, F) and a ctenolium with 2–3 functional teeth. A specimen *c.* 15 mm high already has the byssal notch greatly reduced (Fig. 62A, C, E). The 5 mm-high specimen is only just changing from antimarginal-dominated to commarginal-dominated microsculpture at the valve margin (Fig. 61I), and a similar change can be seen at a height of about 3 mm on the LV in Fig. 61A (change from a paler to a darker shell surface). The RV preradial dissoconch has particularly coarsely reticulate sculpture, as it bears low, narrow radial threads as well as commarginal ridges (Fig. 61C, E, G). The antimarginal ridgelets are visible in the lozenges between the other two sculptural elements. Large adults have a strongly inflated RV and a markedly more weakly inflated LV, with five very wide, convex plicae on the RV and six much narrower ones on the LV. Almost all specimens have remarkably unvaried sculpture of several very wide, low, closely spaced radial costae on RV plical crests, slightly more prominent radial costae on LV plical crests, and few, narrow, prominent radial costae in plical interspaces on both valves. Adult anterior auricles are remarkably similar in size and shape on the two valves, small and with the anterior margin inclined strongly towards the anterior, with the byssal notch almost lost altogether, and posterior auricles are identical on the two valves, very small and short, with a concave posterior margin. All fresh specimens also are magenta near the LV umbo and on LV costae, and white elsewhere, with the RV almost completely white.

Fig. 61. Mesopeplum fenestratum (Hedley), Recent, type species of *Mesopeplum* Iredale, 1929; SEMs of small Recent specimens. A, C, E, G, H, LV, AMS C300341, 70 m, off Cronulla, Sydney, New South Wales; whole shell (A) enlarged, × 9 (H 5 mm), and enlargements of sculpture of preradial dissoconch (C × 30 E × 110, G × 180) and of commarginal disc sculpture near ventral margin (H × 60). B, D, F, I, small RV (H 5 mm), AMS C300342, 128–146 m, off Cape Everard, Victoria; B, whole shell, enlarged, × 9, and enlargements of byssal notch and ctenolium (*D* × 30, *F* × 125) and of disc sculpture near ventral margin (I × 30).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The one exception to the sculptural invariance is the form named *M. triggi* by Cotton & Godfrey (1938: 97, fig. 83), which is based on a few specimens of *M. fenestratum* with slightly coarser radial costae than usual. There is no doubt that this is part of the variation of *M. fenestratum*, and with the inclusion of this variant the species is still less varied than most of the fossil species and, in particular, than *M. convexum*.

As pointed out by Beu (1995: 52), *M. fenestratum* differs from the New Zealand Late Pliocene to Recent species *M. convexum* (Quoy & Gaimard) in several significant characters: (1) *M. convexum* retains a deep byssal notch and functional ctenolium in adults, even though it is free-lying on the seabed, and the most vigorous swimmer of New Zealand pectinids, clapping its valves vigorously and flapping about on the bottom of the boat when newly dredged; (2) *M. convexum* is exceedingly variable in shape and sculpture (varying in the degree of prosocline shape, the inflation, the number and prominence of the plicae, and the number and prominence of the radial costae), quite unlike the almost unvaried *M. fenestratum*; and (3) *M. convexum* also is highly variable in color, from white to deep purple through all shades of yellow, orange and red, and some specimens are uniformly colored all over whereas others are broadly streaked, spotted or radially banded, and only some have the white RV of *M. fenestratum*, others having the same color on both valves; the color pattern of *M. fenestratum*, with the LV umbo and costae picked out in magenta on an otherwise white shell, is not seen in *M. convexum*. Lamprell & Whitehead (1992: pl. 13, fig. 79) included *M. triggi* Cotton & Godfrey in the synonymy of *M. convexum*, but there is no doubt that this is incorrect, and *M. convexum* is a highly distinct species. These differences, along with the very distinct fossil histories of *Mesopeplum* in the two regions, indicate a long period of complete separation between the species now living on the two sides of the Tasman Sea.

The single known post-Bairnsdalian fossil specimen (Fig. 60F) representing a presumed lineage leading from the Middle Miocene *M. incertum* to the living *M. fenestratum* is a RV in a sample of *M. meringae* (Tate) from lower Jemmys Point Formation (Cheltenhamian, Late Miocene) at Lake Tyers, Gippsland. It appears likely that Late Miocene and Pliocene rocks in the Gippsland Basin and in the St Vincent and Murray basins in South Australia were deposited in water too shallow to be inhabited by species of the *M. fenestratum* group. This single fossil differs from Recent specimens of *M. fenestratum* in having a longer RV anterior auricle and retaining a moderately deep, narrow byssal notch and 1 or 2 functional ctenolial teeth, in having much more prominent radial costae on the plical crests, and in having coarser and more prominent commarginal lamellae. The last is a unique character, while the deeper byssal notch and coarser radial costae are characters shared with *M. incertum*. The specimen has unusually deep and prominent internal rib carinae around the interior of the ventral margin, more prominent than in either *M. fenestratum* or *M. incertum*. The prominent carinae may be related to its very prominent costae, as the carinae are very short and located only around the margin in most species of *Mesopeplum*. The specimen also has the ctenolium situated on a well elevated, smooth ridge extending along the edge of the byssal fasciole, as in *M. incertum*. This specimen is therefore not very advanced over the condition seen in *M. incertum*.

Dimensions.

AMS C132125, Recent, off Eden, NSW, 55–73 m	H 44.9	L 46.7	RV
NMV P302112, Lake Tyers Gippsland	39.6	42.2	RV
Holotype of *Chlamys fenestrata* Hedley	19.2	19.1	2 valves
AMS C102330, off Port Kembla, NSW, largest seen	52.1	55.0	2 valves

Type material. *Chlamys fenestrata* Hedley, 1902, holotype, AMS C8971, from 33 m, off Ball's Head, Sydney Harbour, New South Wales, a half-grown shell, with 2 valves articulated; *Mesopeplum caroli* Iredale, 1929, holotype not located in AMS, no material in collection from type locality (neotype required).

Fig. 62. *Mesopeplum fenestratum* (Hedley), Recent, type species of *Mesopeplum* Iredale, 1929. A, C, E, G, small RV (in same collection lot as Fig. 61A, C, E, G, H), H 15 mm: A, most of specimen, enlarged, × 3.7; byssal notch enlarged (C × 12, E × 30); G, disc sculpture near ventral margin, × 15, illustrating false surface formed by commarginal lamellae. B, D, F, H, typical adult specimen, AMS C132125, 55–73 m, off Eden, southern New South Wales: B, D, F, enlarged, × 1.25; H, umbo and anterior auricle enlarged, × 3; B, F, LV, whitened with MgO (B) and uncoated (F) to show color pattern; D, RV, whitened with MgO.

Other material examined. **Cheltenhamian:** JEMMYS POINT FORMATION: NMV P302112, PL3269, point on Trident Arm, Lake Tyers, between northern and southern arms, opposite Trident Arm Track picnic ground; from nodule bed in shore platform. Grid ref. Hospital Creek 001132; coll. A. G. Beu & T. A. Darragh, 21.xi.1993 (1 specimen, with large lot of *M. meringae*, NMV P300961).

Occurrence and time range. No fossils are known to us that agree precisely with *M. fenestratum*. The single Gippsland fossil described under this heading is Cheltenhamian, and seems to be intermediate between *M. incertum* and *M. fenestratum* in the reduction of the byssal notch. Recent specimens occur all around southern Australia from North West Cape, Western Australia (Wells & Bryce 1985: 160), around the coasts of South Australia, Victoria, Tasmania and New South Wales, to southern Queensland (northernmost: AMS C96125, ESE of Noosa heads, southern Queensland, 'Kimbla' sta. 2025, 2 valves; also one valve of dubious reliability in AMS C120099, Great Barrier Reef sta. 14, 'half mile [0.8 km] south of Lizard Island', North Queensland; Iredale 1939: 221).

Tribe Pectinini Wilkes, 1810

Remarks. A diagnosis is provided above, under 'Classification'. The main familiar genera in this tribe are *Pecten*, *sensu stricto*, *Amusium* Röding, 1798, *Amussiopecten* Sacco, 1897, and the American *Pecten* homeomorph *Euvola* Dall, 1898. Of these, only *Pecten* (Quaternary only) and *Amusium* occur fossil in Australia. Both also are conspicuous members of the living fauna, *Pecten* mainly in the temperate south and *Amusium* in the tropical north. A tropical species of *Pecten*, apparently *P. excavatus* Anton, 1839, recently has been collected on the Northwest Shelf of Western Australia (small specimens observed by AGB in WAM), and *Amusium* species extend in small numbers southwards into the temperate zone (to Jervis Bay, New South Wales, on the east coast, and to Albany, south coast of Western Australia. *Amusium* is a significant, speciose genus in Australia, with at least three species occurring as fossils, one of which (*A. balloti* Bernardi) is still living. *A. subcostatum* sp. nov., in Late Oligocene and earliest Miocene rocks, is one of the earliest species recorded in the genus world-wide.

Skwarko et al. (1995: e21–23, f10) recorded eight species of *Amusium* and one each of *Flabellipecten* and *Amussiopecten* from Neogene rocks of Indonesia. Probably not all the species referred to *Amusium* actually belong there. Nevertheless, with the 51 other scallops listed, this catalogue demonstrates that tropical waters to the north of Australia had a significantly more diverse Neogene pectinid fauna than that of southern Australia.

Genus *Amusium* Röding, 1798

Amusium Röding, 1798: 165.

Type species (by subsequent designation, Herrmannsen 1846: 47). *Ostrea pleuronectes* Linné, 1758, Recent, Indo-West Pacific.

Pleuronectes Bronn, 1831: 624.

Type species (by monotypy). *Ostrea pleuronectes* Linné, 1758 (junior homonym of *Pleuronectes* Linné, 1758).

Pleuronectia Swainson, 1840: 388.

Type species (by monotypy). *Pleuronectia laevigata* Swainson, 1840 (= *Ostrea pleuronectes* Linné, 1758).

Remarks. The relationships of *Amusium* have confused many taxonomists over the years, as its prominent internal carinae and absence of external radial sculpture make it a confusing, if not very close, homeomorph of the small mud-pectens of the Family Propeamussiidae. Waller (1972b; 1991: 37–41) stressed the concept that *Amusium* is a close phylogenetic relative of *Pecten*, that has lost its external sculpture and become thin, light and equivalve, with large anterior and posterior shell gapes and almost symmetrical auricles, so that it can swim readily and well to avoid predators, rather than camouflaging itself at the sediment-water interface as *Pecten* does. The similarity to the small mud-pectens is another superficial homeomorphy, as members of the Propeamussiidae have never had coarse external radial sculpture, have a different shell structure and anatomy from those of the Pectinidae, and have evolved single internal radial ribs quite independently of the paired internal rib carinae of *Amusium*, which are the internal expression of former external radial costae. Other fundamental differences between these groups in shell mineralogy and in the distribution of shell layers were pointed out by Waller (1972b).

Amusium subcostatum sp. nov.

Fig 63B, D, E, 64D, E

Description. Small for genus, to 55 mm high and 60 mm long, slightly longer than high, acline, unusually thick and solid for genus, with low, faint, radial corrugations on exterior. Umbonal angle of large specimens up to 120°; anterodorsal margin similar in length to posterodorsal margin, shape of most specimens symmetrical. LV preradial area

apparently *c.* 4 mm high, sculptured only with very faint, low, commarginal corrugations. Radial sculpture of disc of 25–28 extremely low, faint, wide, poorly defined corrugations, each slightly wider than one interspace on RV and slightly narrower than one interspace on LV, more clearly defined as low, narrow, widely spaced costellae over proximal third to half of auricles on some specimens, with very numerous, exceedingly fine, widely spaced, truly radial threads over entire surface. Interior with pairs of narrow, well raised rib carinae, very short near anterior and posterior ends of disc and occupying distal third to half of disc height near centre of disc, carinae in each pair spaced slightly further apart in RV than LV in specimens available, 22 pairs in LV and 23 pairs in RV; each pair ending at narrow, sharp ridge just inside ventral margin of disc, the tips of each pair inclined in slightly towards each other. Auricles very large for genus, almost equilateral and almost the same shape in the two valves, with slightly rounded anterodorsal and posterodorsal extremities, anterior margin weakly sinuous on both valves, with wide, very shallow byssal notch on RV; no ctenolial teeth visible in auricular groove in any specimens available. Auricles separated from disc by being obviously depressed below disc surface, but without undercut groove. Hinge with one pair of obvious, wide, low dorsal teeth in RV and sockets in LV. Base of each auricle with a small, sharply rounded interior nodule a short distance in from valve margin, where auricle margin meets disc margin.

Dimensions.

Holotype, P300332	H 42.7	L 42.7	LV
Paratype, NMV P3876, Torquay	38.7	39.1	LV
Paratype, NMV P300329, Torquay	37.0	39.5	LV
Paratype, NMV P3877, Torquay	55.4	59.2	RV

Type material. Holotype, a LV, NMV P300332, Jan Juc Formation, 'Spring Creek' (= Bird Rock cliffs), Torquay, Victoria, coll. J. Jutson; paratype, a LV, NMV P3876, upper beds, Bird Rock cliffs, Torquay, Victoria (Jan Juc Formation, Janjukian), ex Geological Survey of Victoria; paratype, a RV, NMV P3877, labelled 'Waurn Ponds, near Geelong', but we have seen no other specimens from Waurn Ponds Limestone at Waurn Ponds, and the shelly, pale brown, highly glauconitic matrix of this specimen matches that of specimens from Jan Juc Formation, Torquay, so there is little doubt that is the correct provenance; ex Geological Survey of Victoria; paratype, a LV, NMV P300329, Jan Juc Formation, 'lowest bed (bluish grey sandstone) visible in Half Moon Bay (= zone 1 of Cudmore)', Bird Rock Cliffs, Torquay, Victoria, coll. F. A. Cudmore.

Other material examined. **Janjukian:** JAN JUC FORMATION: PL3024, Bird Rock (4 specimens); PL3025, Fishermans Steps (4 specimens); Spring Creek, Torquay (9 specimens); Torquay, mislabelled 'Waurn Ponds' (2 specimens); Torquay, mislabelled 'Western Beach, Corio Bay' (2 specimens). **Longfordian:** MANNUM FORMATION: PL3182, granite quarry, near Mannum (12 specimens); PL3184, quarry at Taworri (9 specimens); PL3187, quarry at Younghusband (7 specimens); WAM 85.764, small pit by Murray River E bank road, 5.5 km S of Younghusband store (1 specimen).

Occurrence and time range. Janjukian and Longfordian; seen only from Jan Juc Formation at Torquay (Janjukian) and a few small, poor specimens from Mannum Formation (Longfordian), Murray Basin.

Remarks. Amusium subcostatum sp. nov. is very distinct from any of the other Miocene to Recent species of *Amusium* we know of, because of its small size, its wide shape, its thick, heavy shell for an *Amusium* species, its relatively large auricles, which are very much longer in relation to the length of the disc than in any younger species and, above all, its very weak radial sculpture. As far as we are aware, this sculpture is the first recognised on any species correctly referred to *Amusium* on the basis of Waller's (1991, 1993) phylogenetically useful characters [Waller (1991: 38–39) pointed out that American '*Amusium*' species are homeomorphs that have evolved from *Euvola*]. Although slight abrasion of these relatively early fossils makes it difficult to be sure of the LV preradial characters, the holotype appears to be little-enough abraded to be showing the true LV preradial sculpture, and bears only faint commarginal corrugations. This and all the other at least reasonably typical *Amusium* characters of this species indicate that it is correctly referred to *Amusium*, *sensu stricto*, and apparently represents a very early species of the genus that still retains the last vestiges of radial sculpture. The large auricles and the presence of weak external radial costae indicate that this species represents an early stage of evolution of *Amusium* from the ancestral genus *Amussiopecten*, but this transition evidently took place outside southern Australia.

Etymology. The specific name (Latin, '*sub-*', under, less than +'*costatus*', ribbed) refers to the very weak, but definitely present, radial costae of this species.

Amusium morganense sp. nov.

Figs 64A, F, 65A–E

Pecten lucens Tate, 1886: 115 (in part; specimens from 'River Murray cliffs at Blanchetown').

A
B
C
D
E

Description. Rather small for genus (to *c*. 78 mm high), acline to slightly prosocline, weakly inflated, slightly higher than long to slightly longer than high, thin and fragile, similar in general appearance to *A. pleuronectes*. Umbonal angle *c*. 120° in large specimens; posterodorsal disc margin slightly longer than anterodorsal disc margin. LV 'preradial' sculpture not seen. Sculpture of exterior consisting only of weak, fine, close commarginal striae and similar radial striae, but slightly abraded on all specimens; faintly darker radial rays at positions of internal carinae visible through shell in some specimens, as in *A. pleuronectes*. Interior with 30–32 pairs of very narrow, closely spaced carinae in LV, 34 pairs in the one available RV, clearly arranged in pairs, each pair on a more elevated area than the interspaces, weak and obscure over a wider area near anterodorsal margin than near posterodorsal margin; carinae end in short ridges, the ridges of each pair inclined inwards towards each other. Auricles separated from disc by very narrow, shallow grooves; without obvious radial sculpture, relatively large, wide, *c*. 1.25 times the width of auricles on similar-sized specimens of *A. pleuronectes*; RV auricles with dorsal margins diverging outwards dorsally much more markedly than in *A. pleuronectes*, ie., auricles markedly taller than in *A. pleuronectes*, with rounded anterodorsal and posterodorsal extremities; anterior margin of RV anterior auricle with narrow, very shallow byssal notch, very slightly swollen above neighbouring disc surface, margin outline above notch regularly convex; RV posterior auricle with evenly convex outline, inclined slightly towards anterior. LV auricles closely similar to those of *A. pleuronectes*, except that anterior margin of anterior auricle is slightly sinuous, with very shallow byssal sinus occupying lower half of margin. Hinge with one pair of narrow dorsal teeth in RV, narrow sockets in LV. Each auricle with low, rounded nodule at base, just inside valve margin where auricle margin meets disc margin; much lower and less obvious than similar nodules on *A. pleuronectes*.

Dimensions.

Holotype, NMV P302133	H 56.4	L 56.4	LV
Paratype, NMV P302134, Morgan	75.3	75.9	RV
Paratype, NMV P302132 NNE of Blanchetown	H 47.5	L 45.9	LV
Paratype, SAM T970A Blanchetown	68.0	66.4	RV
Paratype, SAM T970B Blanchetown	52.7	51.9	LV

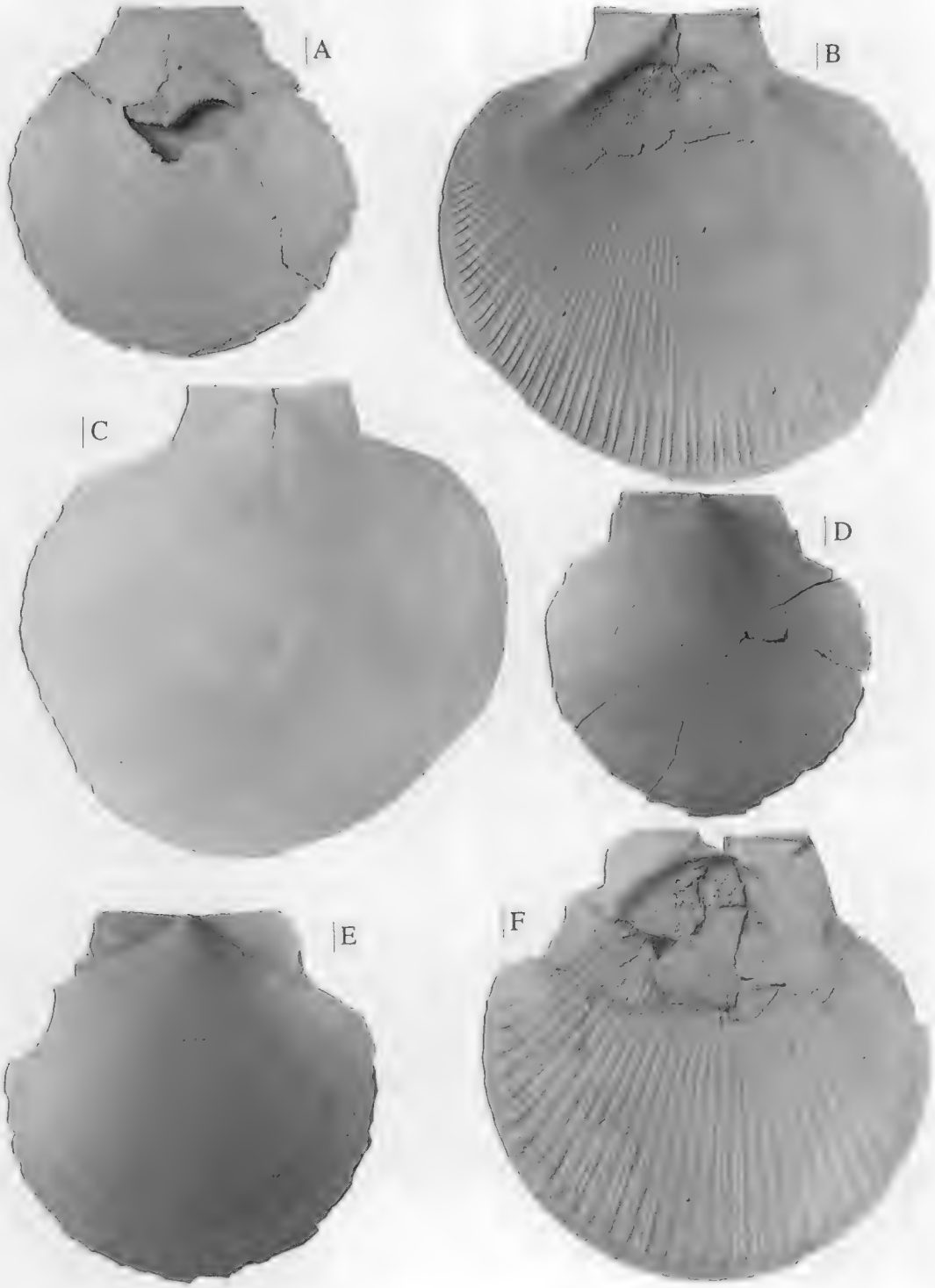
Type material. Holotype, NMV P302133, Morgan Limestone (Balcombian), PL3198, cutting on western approach to Blanchetown bridge, west bank Murray River above Blanchetown, South Australia, grid ref. Blanchetown 723984, coll. A. G. Beu & T. A. Darragh, 23.ix.1993; paratype, NMV P302134, Morgan Limestone, 'white calcareous bed, River Murray cliffs near Morgan, South Australia', coll. F. A. Cudmore, 1919–1929; paratype, NMV P302132, Morgan Limestone, PL3203, cliff on left (east) bank Murray River, about 10 m above lagoon at South Australian Water Ski Assoc. facility, 7 km NNE of Blanchetown, South Australia, grid ref. Blanchetown 753044, coll. A. G. Beu & T. A. Darragh, 25.ix.1993; 3 paratypes, SAM T970A–C, Tate's (1886) paralectotypes of *Pecten lucens*, 'River Murray cliffs at Blanchetown', ie., Morgan Limestone, Balcombian.

Other material examined. **Balcombian:** CADELL MARL: PL3084, Cadell Marl lens (1 specimen); MORGAN LIMESTONE: PL3189, cutting, Mannum pumping station (1 specimen); PL3195, Swan Reach, SA (2 specimens); PL3198, Blanchetown bridge cutting (16 specimens); PL3202, Adams St, Blanchetown (3 specimens); PL3203, South Australian Water Ski Assoc. (19 specimens); PL3205, Woods Flat Post Office (7 specimens); PL3208, Murray cliffs, Great Yarra Reach (3 specimens); white calcareous bed, River Murray cliffs, Morgan district (4 specimens); Tate's bed 9, River Murray cliffs at Morgan (2 specimens); WAM 79.3043, E bank Murray River 6.4 km N of Blanchetown (2 specimens); NULLARBOR LIMESTONE: WAM 67.426, Loongana Quarry (1 specimen).

Occurrence and time range. Balcombian; almost all material is from Morgan Limestone, Murray Basin; one specimen seen from Nullarbor Limestone in the Eucla Basin.

Remarks. *Amusium morganense* sp. nov. is similar to *A. pleuronectes* (type species of *Amusium*) in many characters, but is easily distinguished by its larger auricles, its slightly narrower byssal notch, the much more markedly dorsally diverging dorsal margins of the RV auricles, other more subtle differences in auricle shape, and the very much more numerous, more closely spaced internal rib

Fig. 63. A, C, *Amusium balloti* (Bernardi), LV of lectotype (designated here) of *Pecten lucens* Tate, SAM T969B; see Fig. 64A, C for RV of same specimen; 'oyster bed, Aldinga', ie., Hallett Cove Sandstone (Late Pliocene), coast SW of Adelaide; enlarged, × 1.5; exterior (A) and interior (C). B, D, E, *Amusium subcostatum* sp. nov., Jan Juc Formation (Janjukian), Bird Rock Cliffs, Torquay, Victoria: B, interior of holotype, LV, P300332 (exterior in Fig. 64E), enlarged, × 1.25; D, paratype, RV, P3877, labelled 'Waurn Ponds', but with Jan Juc Formation matrix; enlarged, × 1.25; E, paratype, RV, P3876, enlarged, × 1.5.


A
B
C
D
E
F

carinae, which are clearly arranged in closely spaced pairs. *A. pleuronectes* has 22–34 individual carinae, rather than pairs of carinae (ie., about half the number of carinae of *A. morganense*) and the space between the carinae in each pair is not elevated into costal remnants in *A. pleuronectes* as it is in *P. morganense*, nor are the tips of carinae pairs inclined inwards towards each other as in *A. morganense*. Indeed, the carinae in *A. pleuronectes* are evenly spaced and not obviously arranged in pairs at all, except for 1–2 pairs at the anterior and posterior ends of the disc. The shell size and the shape and inflation of the disc are very similar in the two species, and a few specimens of *A. morganense* are well enough preserved to show faint radial color bands on the exterior (Fig. 65D) corresponding to the internal carinae, as in *A. pleuronectes*. The new species therefore makes a plausible member of a lineage leading to the Recent *A. pleuronectes*.

A single LV (Fig. 65E) from Nullarbor Limestone (Middle Miocene) has the large auricles and numerous, closely spaced, clearly paired internal carinae of *A. morganense*, and appears to be a typical specimen of the new species. It occurs in Nullarbor Limestone (WAM 67.426) with poorly preserved specimens of a much larger species, similar to *A. balloti*.

Etymology. The specific name ('from Morgan') refers to the origin of this species from the Morgan Limestone.

Amusium balloti (Bernardi, 1861)

Figs 63A, C, 64B, C, 66A–H

Pecten balloti Bernardi, 1861: 46, pl. 1, fig. 1.
Amussium [*sic*] *balloti*; Angas, 1877: 193.
Pecten lucens Tate, 1886: 115 (in part; 'oyster beds, Aldinga Bay' specimens only).
Pecten (Amussium) [*sic*] *milneedwardsi* Gregorio, 1883: 133; 1898: 6, pl. 1, figs 2, 6; pl. 3, fig. 2; pl. 4, fig. 1.
Pecten (Amussium) [*sic*] *balloti*; Gregorio, 1898: 7, pl. 1, figs 3, 4, 7; pl. 4, fig. 4.
Pecten (Amussium) [*sic*] *tatei* Gregorio, 1893: 133; Gregorio, 1898: 39 (unnecessary replacement name for *P. lucens* Tate, 1886, not preoccupied by *Pecten (Pleuronectia) lucidus* Jeffreys, 1872 (*nomen nudum*), = *Pleuronectia lucida* [Jeffreys MS] Wyville Thomson, 1873).
Amusium lucens; Tate, 1899: 272 (in part).
Amusium japonicum; Hedley, 1918: M9 (not *Ostrea japonica* Gmelin, 1791).
Amusium balloti; Iredale, 1939: 369; Allan, 1950: 282, pl. 31, fig. 15; Coleman, 1975: 261, fig. 712; Wells & Bryce, 1985: 158, fig. 579; Dijkstra, 1988: 3, unnumbered figs; Rombouts, 1991: 3, pl. 2, fig. 5a; Lamprell & Whitehead, 1992, pl. 7, fig. 38.
Amusium ballotti [*sic*]; Garrard, 1961: 5.
Amusium japonicum balloti; Habe, 1964: 4, pl. 1, fig. 5; pl. 2, fig. 6; Wang, 1984: 250, fig. 6; Waller, 1991: 37, pl. 8, figs 5, 8.

Description. Large (to 140 mm high), almost circular, acline, height about equal to or slightly greater than length; superficially smooth and polished; umbonal angle very wide (to *c.* 145°); weakly inflated, the two valves equally inflated; articulated shells gaping markedly at anterior and posterior ends. Exterior sculptured only with weak, faint, irregular commarginal corrugations and occasional faint radial striae. Interior bearing 42–54 narrow, prominent radial carinae, arranged clearly in pairs. RV anterior auricle with shallow but obvious byssal notch, 6–7 low, narrow radial costae above byssal fasciole, and weak but functional ctenolium in juvenile specimens (to *c.* 20 mm high), all three progressively reduced in larger specimens, notch at most a shallow sinuosity in otherwise weakly convex anterior margin in adults; RV auricles smooth and almost symmetrical in adults, anterior and posterior margins weakly to quite strongly convex in outline, sloping weakly towards umbo, dorsal margins weakly serrate; LV auricles smooth, symmetrical, with weakly to quite strongly convex anterior and posterior margins sloping in towards umbo. Hinge very weak, with only thin dorsal teeth obvious. Thickened valve abutting surfaces forming obvious low, rounded nodule on both anterior and posterior inside auricle bases.

Fig. 64. A, F, *Amusium morganense* sp. nov., 2 LVs, paratypes, and paralectotypes of *Pecten lucens* Tate, both from Morgan Limestone (Balcombian), 'River Murray cliffs at Blanchetown', South Australia; at natural size: A, SAM T970C, exterior; F, SAM T970A, interior. B, C, *Amusium balloti* (Bernardi), RV, lectotype of *Pecten lucens* Tate, SAM T969B, 'oyster bed, Aldinga', ie., Hallett Cove Sandstone (Late Pliocene), coast SW of Adelaide; LV of same specimen in Fig. 63A, C; enlarged, × 1.5; B, interior; C, exterior. D, E, *Amusium subcostatum* sp. nov., Jan Juc Formation (Janjukian), Bird Rock Cliffs, Torquay, Victoria, all enlarged, × 1.25: D, paratype, P300329, LV, from 'lowest bed (bluish grey sandstone) visible in Half Moon Bay', ex Cudmore Coll.; E, holotype, LV, P300332, exterior (interior in Fig. 63B).

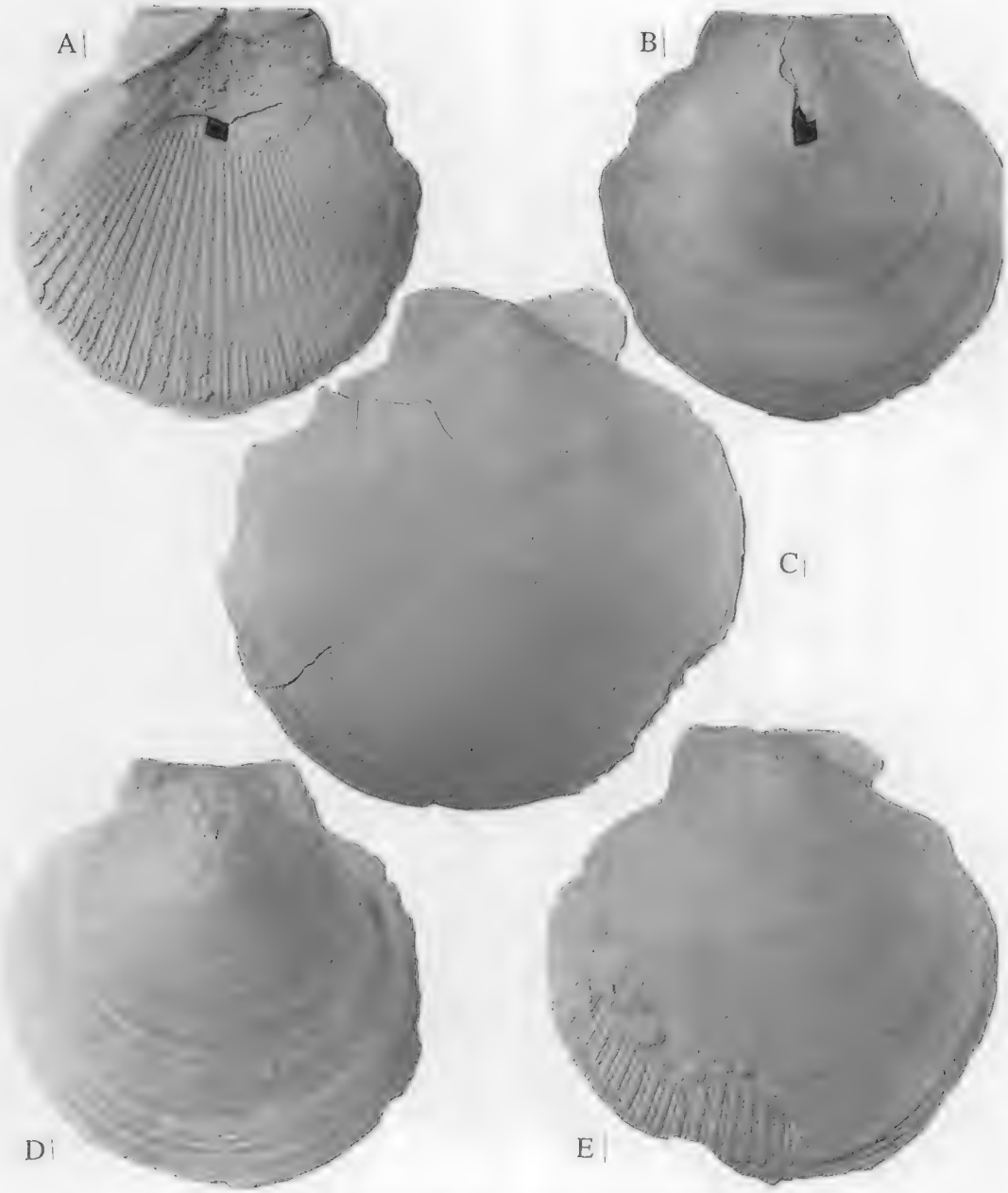


Fig. 65. *Amusium morganense* sp. nov., Balcombian. A–D, from Morgan Limestone, Murray River, South Australia: A, B, holotype, P302133, interior and exterior of LV, PL3198, cutting on west side Blanchetown bridge; at natural size; C, paratype, large RV, P302134, 'white calcareous bed, River Murray cliffs near Morgan', ex Cudmore Coll., at natural size; D, paratype, small LV, P302132, exterior, uncoated, to show faint radial color bands coinciding with internal rib carinae; from same collection as holotype; enlarged, × 1.25. E, RV, partial abraded exterior (dorsal margin incomplete), posteroventral margin an internal mould, WAM 67.426, Nullarbor Limestone, Loongana Quarry, Nullarbor Plain; at natural size.

Dimensions.

Lectotype of *Pecten lucens* Tate	H 47.8 47.6	L 49.2 48.2	RV LV
Paralectotype, SAM T969A 'Aldinga'	93.7	96.2	2 valves
NMV P300354, Port Willunga	94.5	94.0	2 valves

Type material. *Pecten lucens* Tate, 1886, lectotype designated here, SAM T969B, C, smaller, paired, clean specimen from 'oyster beds, Aldinga Bay', ie., Hallett Cove Sandstone, Late Pliocene; one paralectotype, SAM T969A, large specimen, all data as for lectotype; 3 paralectotypes, specimens of *A. morganense* sp. nov., SAM T970A–C, 1 RV and 2 LVs, from 'River Murray cliffs at Blanchetown', ie., Morgan Limestone, Balcombian. *Pecten balloti* Bernardi, 1861, 3 syntypes in Muséum National d'Histoire Naturelle, Paris, from 'Nova-Caledonia' (Dijkstra & Marshall 1997: 95). Gregorio's (1898: 39) replacement name *Pecten (Amussium)* [*sic*] *tatei* was unnecessary, and being a replacement name, has no separate type material; the location of the type material of Gregorio's (1898: 6) synonym *Pecten (Amussium)* [*sic*] *milneedwardsi* is not known to us.

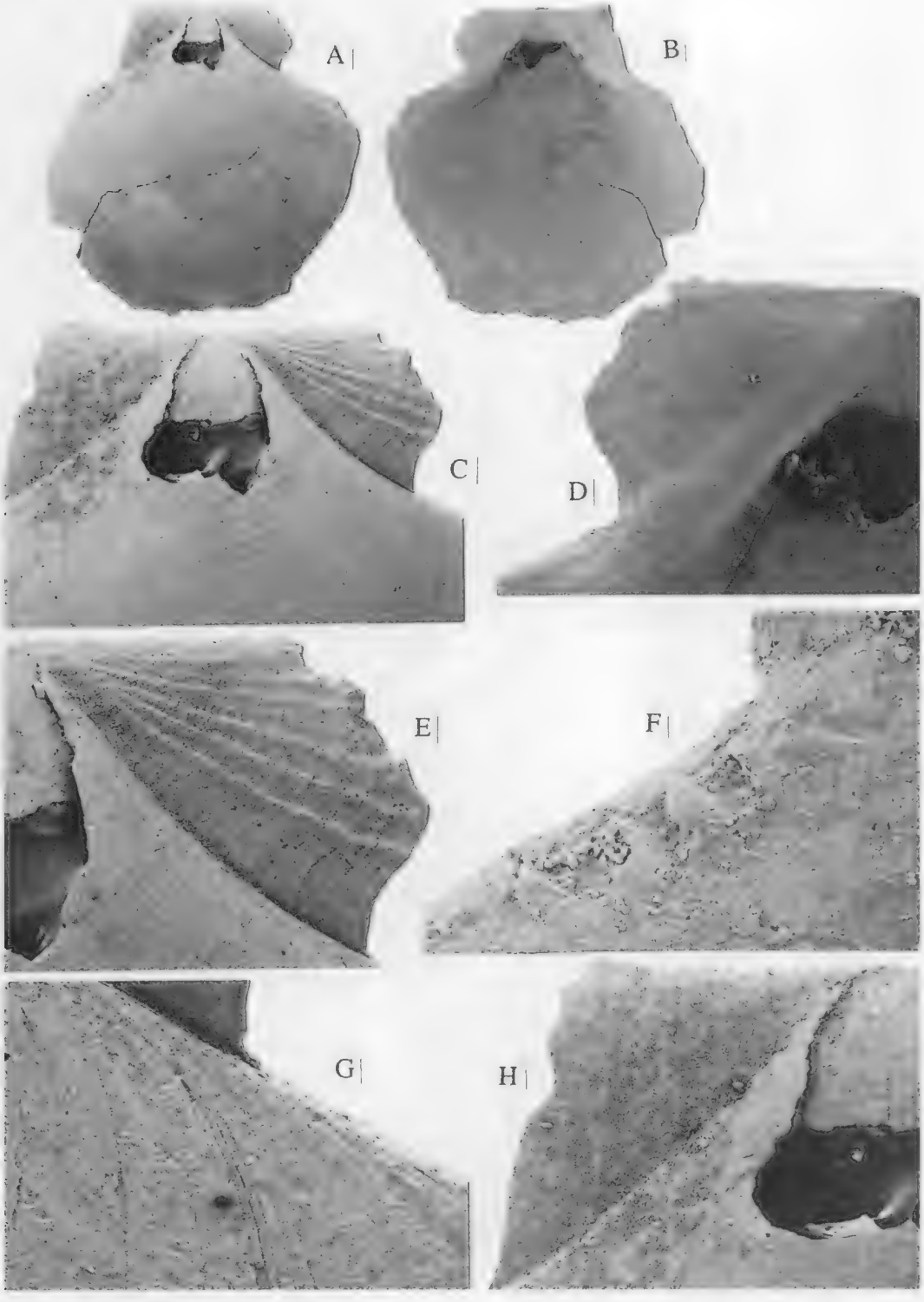
Other material examined. **Cheltenhamian:** JEMMYS POINT FORMATION: PL3127, Mississippi Creek tramway terminus (1 fragment). **Late Pliocene:** HALLETT COVE SANDSTONE: Port Willunga (1 specimen); Aldinga (1 specimen); NORWEST BEND FORMATION: PL3179, Fred's Landing, Tailem Bend, Murray River (10 specimens); 'OLDER' ASCOT FORMATION, Perth Basin: WAM 73.167, 28.3–29.5 m, Kowalski's bore, corner Bullfinch and Balfour streets, Huntingdale (1 fragment); WAM 76.955, 15.2–18.3 m, Eaton's bore, Wharf St, Queens Park (6 fragments with clearly paired internal carinae); WAM 85.590, 28.6–40.4 m, Jupp's No. 1 bore, Gingin Brook Rd, West Gingin (3 fragments).

Occurrence and time range. Cheltenhamian to Recent. Pliocene, 'older' Ascot Formation, Perth Basin, Hallett Cove Sandstone and Norwest Bend Formation in the St Vincent Basin, and a single record from Jemmys Point Formation in the Gippsland Basin. The absence from Roe Calcarenite is surprising, and could indicate a preference for siliciclastic substrates rather than calcareous ones, however, its absence from the siliciclastic 'younger' Ascot Formation is just as striking, and perhaps indicates cooler temperatures during Early Pleistocene time in the Perth Basin than at present.

A large *Amusium* species in Nullarbor Limestone (Balcombian) (WAM 67.426) is very similar to *A. balloti*, although the small amount of poorly preserved material we have seen makes comparison difficult. *A. morganense* sp. nov. is recorded above from the same formation; this is the only example we have seen in Australia where two *Amusium* species are possibly present in the one formation.

Remarks. *Amusium balloti* is the larger of the common, large, commercially fished 'saucer scallops', occurring commonly at present from Albany, southern Western Australia, around northern Australia to northern New South Wales, and rarely as far south as Jervis Bay, southern New South Wales (Smith 1992). It occurs also in New Caledonia (type locality of *Pecten balloti* Bernardi). Habe (1964) ranked *A. balloti* as a geographic subspecies of the Japanese saucer scallop, *A. japonicum* (Gmelin), but Wang (1984) recorded all three 'subspecies' *A. japonicum japonicum*, *A. japonicum balloti* and *A. japonicum formosum* Habe occurring in the South China Sea. Dijkstra (1991) recorded *A. balloti* from Indonesia, pointing out consistent differences from *A japonicum* (Gmelin) and Dijkstra & Marshall (1997) pointed out that *A. balloti* is the most widespread western Pacific large *Amusium* species, occurring in the Philippine archipelago, where *A. japonicum* is not recorded, and that they knew of no intermediate specimens between *A. balloti* and *A. japonicum*. We therefore concur with the view that *A. balloti* is a species distinct from *A. japonicum*.

Specimens of the form identified by Tate (1886) as *Pecten lucens* from the Late Pliocene Hallett Cove Sandstone in the St Vincent Basin and other specimens from southern outcrops of Norwest Bend Formation in the Murray Basin are indistinguishable from the living Australian *Amusium balloti*. This is in contrast to the specimens Tate included in the same species from 'calciferous sandstone of the River Murray cliffs at Blanchetown' (= Morgan Limestone, Balcombian), which belong in *A. morganense* sp. nov., described above. *A. morganense* is a much smaller species more nearly related to the smaller living saucer scallop, *A. pleuronectes* (Linné), than to *A. balloti*. Tate's (1886) material identified as *P. lucens* from 'oyster beds, Aldinga Bay' (Hallett Cove Sandstone) consists of a large, slightly incomplete specimen, still articulated and filled with matrix and with cemented matrix attached to part of the exterior, and an excellent, half-grown shell with both valves free and clean; the latter is designated above as the lectotype. The larger specimen evidently is the one Tate (1886) was referring to when he said 'my largest specimen measures 100 millimetres in the diameters'. However, Tate (1886) did not illustrate this species, and so the selection of a lectotype is not helped by being able to choose his figured specimen. We have compared Tate's material (Figs 63A, C, 64B, C) and a few other Hallett Cove Sandstone specimens, together with two large, incomplete specimens we collected from Norwest Bend Formation near Tailem Bend, with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H

modern Australian material of *A. balloti*, and found them to be closely similar in shape, inflation, gapes, auricle shape and size including the shape of the byssal notch, and number of internal carinae. We are satisfied that Tate's specimens of *Pecten lucens* from Hallett Cove Sandstone, including the lectotype, are identified correctly as *A. balloti* (Bernardi).

Amusium balloti occurs in northern Australia (as it does throughout the western Pacific) alongside the smaller saucer scallop, *A. pleuronectes*. Size alone provides the most useful character distinguishing them; *A. balloti* commonly reaches 120 mm high, and Iredale (1939: 369) recorded a 'series' dredged in Sydney Harbour by the 'Triton', reaching 140 mm high and 135 mm long; whereas *A. pleuronectes* reaches only about 80 mm high. The two differ also in auricle shape, the RV auricles being more rounded in *A. pleuronectes* than in *A. balloti*. The exterior also differs in color between the two; the RV is largely white in both, whereas the LV of *A. pleuronectes* is pale to medium pink rayed with pale grey (the rays conforming to the internal carinae) and the RV of *P. balloti* is medium to dark brownish red with alternating paler and darker commarginal bands and random darker spots. They also differ in the number and spacing of the internal carinae, *A. pleuronectes* having 22–34 widely spaced carinae in the RV whereas *A. balloti* has 42–54 more closely spaced ones in the RV. Although the carinae are further apart in *A. balloti* than in earlier fossils such as *A. morganense*, they are still visibly paired, ie., there are wider spaces between alternate, slightly more closely spaced pairs than between members of one pair; whereas in *A. pleuronectes* only the few, very short anterior and posterior carinae are arranged in pairs, and all the long ones across the centre of the disc are evenly spaced.

A juvenile specimen, 11.8 mm high, of *A. balloti* (Fig. 66A–H) from Norwest Bend Formation at Fred's Landing, Tailem Bend, Murray River, demonstrates that the dissoconch starts out with a functional byssal notch and ctenolium, with minute, very low, relatively wide ctenolial teeth, and with radial costae on the RV anterior auricle, but later loses both these characters. It is also just starting to develop faint internal carinae at this size.

Genus ***Pecten*** Müller, 1776

Pecten Müller, 1776: 248.

Type species (by subsequent designation, Schmidt 1818). *Ostrea maxima* Linné, 1758, Recent, northeastern Atlantic.

Remarks. As *Pecten* is given only passing mention here, having arrived in Australia (and New Zealand) only during the Pleistocene, we do not list in full the enormous generic synonymy of *Pecten, sensu stricto*. The synonyms are listed, at least in part, by Hertlein (1969: N366–N367). Suffice to say here that we agree entirely with Fleming (1957) and Waller (1991: 37–38) that such names as *Oppenheimopecten* Teppner, 1922 and *Notovola* Finlay, 1926 are synonyms of *Pecten*.

Pecten is easily recognised in the Cenozoic fauna of Australia and New Zealand by its flat or even slightly concave LV, its deeply convex RV, its almost completely symmetrical auricles, and its broad, prominent radial costae on the RV, and correspondingly narrow costae on the LV. The Australasian species (like most of their congeners) have an unusually prominent hinge for a pectinid, with numerous prominent intermediate teeth, and their other highly distinctive character that is important in phylogeny is the very large (up to about 8 mm high) smooth area on the umbo of both valves, before inception of the costae, reflecting the unusually prolonged prismatic outer layer stage on the RV (Waller 1972b, 1991).

Pecten fumatus Reeve, 1852

Pecten medius Lamarck, 1819: 163; Deshayes, 1836: 130; Hedley, 1902: 303; Pritchard & Gatliff, 1904: 261; May, 1921: 10; May, 1923: pl. 3, fig. 5; Iredale, 1924: 193; Finlay, 1926: 451; Cox, 1929: 203; Fleming, 1951: 129, pl. 17, figs 1–4; Rombouts, 1991: 51, pl. 19, fig. 4; Dijkstra, 1995: 470, pl. 1, figs 1, 2 (junior secondary homonym of *Pecten medius* Bosc, 1802).

Fig. 66. *Amusium balloti* (Bernardi), SEMs of small juvenile RV (H 11.8 mm), P300276, Norwest Bend Formation (Late Pliocene), PL3179, Fred's Landing Reserve, 3 km S of Tailem Bend, Murray River, South Australia. A, B, interior and exterior of whole specimen, × 4; in B, note faint signs of internal rib carinae developing; auricles enlarged (C × 10, E, H × 20), showing radial costae on anterior auricle (lost in adult) but smooth posterior one, apart from growth ridges; G, disc margin anterior to anterior auricle, × 60, showing commarginal growth ridges, faint antimarginal ridgelets, and faint signs of ctenolium; interior of anterior auricle (D × 15) and enlargement of margin just below base of auricle (F × 130), showing low, elongate ctenolial teeth.

Pecten ziczac var. B Lamarck, 1819: 164; Deshayes, 1836: 131.
Pecten fuscus 'Klein' G. B. Sowerby II, 1842: 47, pl. 16, figs 118, 119 (not of Bosc, 1802).
Pecten bifidus Menke, 1843: 35 (junior homonym of *Pecten bifidus* Münster in Goldfuss, 1836).
Pecten lamarckii Chenu, 1843: 2, pl. 9 [1844], fig. 7a,b (new name for *Pecten ziczac* var. B of Lamarck; junior homonym of *Pecten lamarckii* Defrance, 1825).
Pecten fumatus Reeve, 1852 [November]: pl. 7, fig. 32; Tenison Woods, 1878: 56; Tate, 1887a: 108; Fleming, 1951: 132; Woodburn, 1990: 226; Rombouts, 1991: 50, pl. 18, fig. 8; Lamprell & Whitehead, 1992: pl. 14, fig. 83; Dijkstra & Marshall, 1997: 91, pl. 13, figs 1, 2.
Pecten modestus Reeve, 1852 [December]: pl. 11, fig. 41; Fleming, 1957: 36 (junior secondary homonym of *Pecten modestus* Bosc, 1802).
Vola fumata; Angas, 1868: 933.
Pecten (Janira) fumatus; Smith, 1885: 307.
Pecten fumatus var. *albus* Tate, 1887a: 115.
Pecten meridionalis Tate, ex Brazier MS, 1887a: 115; Rombouts, 1991: 52, pl. 19, fig. 3 (junior homonym of *Pecten meridionalis* Eichwald, 1865).
Notovola alba; Cotton & Godfrey, 1938: 92, fig. 78; Cotton, 1961: 96, fig. 81.
Notovola fumata; Iredale, 1939: 365; Iredale & McMichael, 1962: 11.
Notovola preissiana Iredale, 1949: 19.
Notovola meridionalis; Allan, 1950: 279, pl. 39, fig. 1.
Pecten jacobaeus byronensis Fleming, 1955: 108, fig. 1; Fleming, 1957, pl. 7, fig. 3.
Pecten benedictus fumatus; Fleming, 1957: 33, pl. 1, fig. 5 [lectotype].
Pecten benedictus albus; Fleming, 1957: 33, pl. 2, fig. 1; Ludbrook, 1978: 47; Ludbrook, 1984: 162, 279, fig. 40a.
Pecten jacobaeus meridionalis; Fleming, 1957: 39, pl. 7, fig. 4.
Pecten modestus modestus; Fleming, 1957: 36, pl. 7, figs 5, 6.
Notovola byronensis; Iredale & McMichael, 1962: 11.
Notovola meridionalis; Iredale & McMichael, 1962: 11.
Pecten alba [*sic*]; Macpherson & Gabriel, 1962: 300, fig. 341; Macpherson, 1966: 231.
Pecten fumatus '*meridionalis*'; Waller, 1991: 37, pl. 8, figs 13, 14.

Remarks. The taxonomic and nomenclatural confusion that has reigned for more than a century over the correct name for the Australian *Pecten* species, and how many species there are, recently has been resolved by two very different lines of research:

(1) Woodburn (1990) demonstrated that there is insignificant genetic distinction between all the eastern Australian *Pecten* forms for them to be regarded even as geographic subspecies, and there is only slight distinction between the Western Australian population (*modestus* of most authors, = *Notovola preissiana* Iredale, 1949) and the eastern population. Since the publication of Woodburn's paper, this slight distinction has been regarded by many malacologists (eg., J. H. Black, pers. comm.; W. F. Ponder, pers. comm.) as merely a function of the great geographic distance between Woodburn's samples, as she had none from the southern coasts of South Australia or Western Australia. The frequently voiced opinion of many Australian malacologists that only one taxon in *Pecten* inhabits the southwestern, southern and southeastern coasts of Australia is now considered to be reasonably well proven.

(2) Dijkstra (1995: 470–472), in reviewing Lamarck's pectinid types, clarified the application of the long-debated name *Pecten medius* Lamarck. The lectotype, designated by Dijkstra (1995) from Lamarck's material in MNHN, Paris [the designation by Fleming (1951: 129) being considered by Dijkstra (1995) to be invalid], is a specimen of the form named *Pecten meridionalis* by Tate (1887a). However, this name, like all others proposed for Australian Recent *Pecten* taxa before 1852, is preoccupied. The earliest available name for the single Australian species is *P. fumatus* Reeve, 1852.

Dijkstra (1995) considered that the names *P. fuscus* G. B. Sowerby II, 1842, *P. medius* Lamarck, 1819 and *P. modestus* Reeve, 1852, all were preoccupied by Bosc (1802). However, as was pointed out by Cox (1929), these are all secondary homonyms, as Bosc was merely reassigning names proposed in *Ostrea* by Gmelin (1791). Nevertheless, this does not affect their current status, as all three were recognised as homonyms and either expressly replaced or had another available name used in their place well before 1961, and so are permanently invalid under ICZN Article 59.3.

We therefore proceed with the assumption that there is only one Australian temperate *Pecten* species, *P. fumatus* Reeve. Our sole purpose here is to record the older fossils of *P. fumatus*. This highly distinctive genus, with the LV flat or slightly concave and the RV highly inflated, or bowl-shaped, is a reliable guide to Pleistocene and younger age in both Australia and New Zealand. Australian records seem to extend back to about the Plio-Pleistocene boundary (*c.* 1.8 my), although it arrived significantly more recently in New Zealand, only a little more than one million years ago. The succession on the Glenelg River, western Victoria, in which the Plio-Pleistocene boundary in Australia was identified by Singleton et al. (1976) is condensed, and it is unclear whether the

incoming of *Pecten* in this section is situated at the base of or somewhere within the Pleistocene. The critical succession for demonstrating the Early Pleistocene arrival of *Pecten* in southern Australia is therefore in the Perth Basin. Here, the 'younger' Ascot Formation, accessible only from water bores, lacks the younger *Hartungia* species, *H. chavani* (see 'Biostratigraphy', above) and contains both *Mimachlamys heterophyseta* sp. nov. and *Zenatiopsis ultima* Darragh & Kendrick, and appears to correlate with the Early Pleistocene Memana Formation of Flinders Island. Several small but excellent specimens of *Pecten fumatus* have been collected from 'younger' Ascot Formation, and it is this unit that provides the best stratigraphic constraints on the arrival of *Pecten* in southern Australia.

Since the species is so well studied, most of the conventions used in the taxonomic sections above are irrelevant here; we merely list the early fossil *Pecten* material we have examined (most younger Pleistocene–Holocene fossils are not listed). Type material of the Recent nominal taxa listed in the synonymy was listed by Dijkstra (1995) and Dijkstra & Marshall (1997).

Material examined. **Early Pleistocene:** 'YOUNGER' ASCOT FORMATION, Perth Basin: WAM 72.4, 43.2 m, Forest Dept settlement bore, Forestry Rd, Myalup (1 specimen); WAM 72.16, 42.7–43.2 m in above bore (1 specimen); WAM 73.596, 32.4 m, Jandakot Cement Works bore, Parkes Rd, Yangebup (1 specimen); WAM 77.2674, 31.7–32.9 m, Murdoch University No. 2 bore (1 specimen); WAM 77.2676, 32.9 m in above bore (1 specimen); WAM 77.2682, 34.5 m in above bore (2 specimens); WAM 77.2735, depth uncertain in above bore (4 specimens); MEMANA FORMATION, FLINDERS ISLAND (all material fragmentary): PL1207, dam D on 'Brunah' (2 specimens); PL1217, dam B on 'Marapana' (1 specimen); PL1218, dam on Oakenfull's (1 specimen); PL1276, dam on block 76 (1 specimen) [these specimens are from more southern outcrops of Memana Formation, where there appears to be no overlying younger sequence to contaminate collections; Last Interglacial–Holocene shellbeds and recent uplift of Flinders Island were described by Murray-Wallace & Goede (1995)]; WHALERS BLUFF FORMATION: PL3155, quarry, Killara Plantation Rd (100+ specimens); Caldwells Cliff, Glenelg River N of Dartmoor (12 specimens); cliff, Glenelg River, allot. 3, Parish of Dartmoor (1 specimen); cliff NE corner Dartmoor township (1 specimen); cliff S of Glenaulin Creek–Glenelg River junction (2 specimens); A.E. Knight's bore, W bank Glenelg River 160 m S of railway bridge at Dartmoor (14 specimens). **Middle Pleistocene–Holocene:** Picnic Point, Hampton (1 specimen); new canal cutting, Melbourne, at 8 m, between wharf and Fishermans Bend (3 specimens); Screw Creek, Inverloch (1 specimen). Present in the Middle and Late Pleistocene and Holocene of the Perth Basin (G.W. Kendrick, July 2000, pers. comm.).

Pectinidae, not determined, A

Fig. 67A–C

Remarks. We offer some comments here on two distinctive pectinids in Nullarbor Limestone (Middle Miocene) that we do not know enough about to be able to place in genera or tribes. The main problem with an identification of the first of them is that all four reasonably complete available specimens with the exterior exposed are LVs (the first two lots listed below). They are well inflated, longer than high, acline, of aequipectinoid shape, with 16–18 wide, prominent, undivided, evenly rounded radial costae, radial interspaces each a mirror image of a costa, and a single, low, narrow, smooth secondary costella in each radial interspace over the central area of the disc (ie., between the major, coarse costae, but not on the anterior and posterior ends of the disc, where the costae are lower and narrower than on the centre). The major costae are crossed by low, narrow, widely spaced (*c.* 2 mm apart), regularly sinuous commarginal ridges, curved with the apex of the curve convex towards the dorsum on the costal crests, and convex towards the ventral margin in the interspaces. The anterior auricle is large and elongate, weakly sculptured, with only *c.* 5 narrow, widely spaced radial costae on the most complete auricle, and with a sinuous anterior margin sloping strongly towards the anterior. The shell material is recrystallised, but all specimens show signs of former antimarginal ridgelets in some of the radial interspaces, and particularly on the anterior and posterior ends of the disc. The antimarginal ridgelets suggest that this is a chlamydinine, whereas the large, coarse, undivided costae suggest that it might belong in one of the more advanced tribes. Without knowledge of the RV, and in particular its anterior auricle, and of the internal characters, it is impossible to suggest an identity of this species, although the aequipectinoid form and the sinuous commarginal ridges suggest a position in Tribe Aequipectinini.

Dimensions.	NMV P302151	H 39.5	L 41.2	LV
	AMS C305946	37.8	43.3	LV
	AMS C305946	44.1	43.6	LV

Material examined. **Balcombian:** NULLARBOR LIMESTONE: NMV P302151, Watson, 42 km S of Maralinga, SA, pres. Mobile Quarries, ex Geological Survey of Victoria, GSV 54719 (2 specimens); AMS C305946, Watson, SA, on Trans-Australia Line, Nullarbor Plain, 30°29'S,131°30'E (2 specimens); WAM G7506, 15 m in railway ballast quarry, 29 km from Forrest, WA (1 specimen); WAM 62.144, Cocklebiddy, Nullarbor Plain (2 specimens); WAM 67.427, Loongana Quarry, Nullarbor Plain (1 specimen);

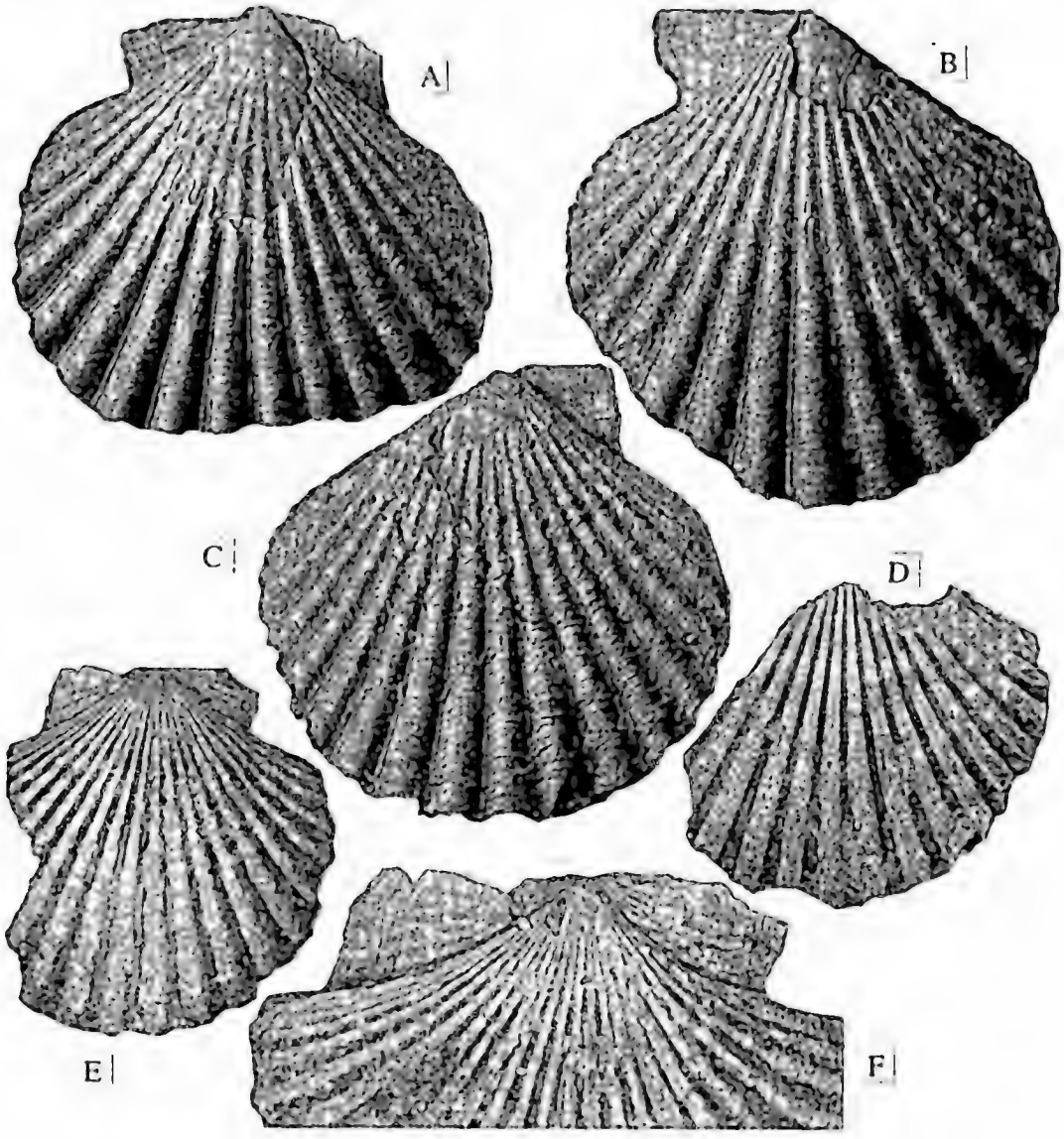

Fig. 67. Unidentified pectinids from Nullarbor Limestone (Bałcombian), Eucla Basin. A–C, Aequipectinini?, LVs, all from trans-Australia railway, Watson, 42 km S of Maralinga, Nullarbor Plain, South Australia: A, B, AMS C305946, C, P302151. D–F, *Annachlamys*? sp., from Monita Tank, Nullarbor Plain, southeastern Western Australia, specimens illustrated by Ludbrook (in Lowry 1970: fig. 34D, E): D, GSWA F6769/1, LV?, interior of incomplete valve, showing prominent rib carinae, at natural size; E, F, GSWA F6769/2, RV exterior, incomplete valve at natural size, and auricles enlarged, × 2.

WAM 67.428, as above (1 specimen); WAM 67.421, as above (1 specimen); WAM 67.432, as above (1 specimen); WAM 73.82, Moonera Tank Cave, Madura district (1 specimen).

Pectinidae, not determined, B

Fig. 67D–F

Pecten murrayanus; Ludbrook in Lowry 1970: fig. 34D, E (not *Pecten murrayanus* Tate, 1886).

Remarks. The second unidentified Nullarbor Limestone species is similar to the first in general appearance, having the same strong inflation, coarse radial costae of rounded section, RV apparently markedly more inflated than the LV, and acline, aequipectinoid shape. The auricles are similar in shape to those of the above species, almost equal and symmetrical, with 4 or 5 weak, narrow radial costae as in the above species. The present species differs from the one described above in lacking the widely spaced, sinuous commarginal ridges and the single low, narrow but obvious radial costa in each interspace between the major radial costae. Several incomplete interiors in the same collections as the present species demonstrate (if they really are conspecific) that this species has prominent, sharp-edged internal rib carinae (Fig. 67D). The illustration by Ludbrook (in Lowry 1970: fig. 34E) apparently was photographed under very low, oblique light, producing dark shadows in the intercostal spaces that make the costae appear square-edged, but the softer lighting used here shows the semicircular costal cross-section more correctly. The very fine, low, closely spaced commarginal ridges crossing the floors of the radial interspaces suggest that the present species actually belongs in Tribe Decatopectinini and possibly is a species of *Annachlamys*. However, it differs from *A. murrayana* in the RV being markedly more inflated and the LV apparently being less inflated (we are not certain that we have examined the associated LV), in having wider, higher radial costae and narrower interspaces, and in lacking the obvious, coarse commarginal ridges of *A. murrayana*. Again, better material is needed to be sure of the characters and relationships of this species.

Dimensions.

Illustrated specimen	H 50	L (incomplete) 43 mm

Material examined. **Balcombian:** NULLARBOR LIMESTONE: Monita Tank, Nullarbor Plain (GSWA F6769/1 and 2; specimens illustrated by Ludbrook, in Lowry 1970: fig. 34D, E).

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Appendix. Key to Museum Victoria fossil locality numbers.

PL506 Nanarup Lime Quarry at Lower Kalgan, Nanarup, Western Australia. Werrillup Formation, Nanarup Limestone Member, Late Eocene, Aldingan.

PL508 Cutting on approach to Jervois Punt and in car park just to the S, left bank Murray River, Tailem Bend, South Australia, AMG Wellington 593 971. Norwest Bend Formation, Pliocene.

PL529 Large quarry to S of Prince's Highway, Waurn Ponds (Old 'Waurn Ponds' quarry), Victoria. Waurn Ponds Limestone, Late Oligocene, Janjukian.

PL1202 Dam A on 'Brunah' property (Conway), Back Line Road, 3.1 km NE of junction of Wingaroo (No. 2A) and Back Line (No. 11) roads, Memana, Flinders Island, Tasmania. AMG Flinders Island (Special) 924 811. Memana Formation, Plio-Pleistocene.

PL1205 Dam B on 'Brunah' property (Conway), Back Line Road, 2.5 km NNE of junction of Wingaroo (No. 2A) and Back Line (No. 11) roads, Memana, Flinders Island, Tasmania. AMG Flinders Island (Special) 912 814. Memana Formation, Plio-Pleistocene.

PL1206 Dam C on 'Brunah' property (Conway), Back Line Road, 2.3 km NE of junction of Wingaroo (No. 2A) and Back Line (No. 11) roads, Memana, Flinders Island, Tasmania. AMG Flinders Island (Special) 915 809. Memana Formation, Plio-Pleistocene.

PL1207 Dam D on 'Brunah' property (Conway), Back Line Road, 2.3 km NE of junction of Wingaroo (No. 2A) and Back Line (No. 11) roads, Memana, Flinders Island, Tasmania. AMG Flinders Island (Special) 918 807. Memana Formation, Plio-Pleistocene.

PL1208 Dam E on 'Brunah' property (Conway), Back Line Road, 2.5 km NE of junction of Wingaroo (No. 2A) and Back Line (No. 11) roads, Memana, Flinders Island, Tasmania. AMG Flinders Island (Special) 921 806. Memana Formation, Plio-Pleistocene.

PL1215 Dam on SW side of Wingaroo (No. 2A) Road, 1.8 km NW of junction of Wingaroo (No. 2A) and Melrose (No. 2) roads, Memana, Flinders Island. Tasmania. AMG Flinders Island (Special) 909 779. Memana Formation, Plio-Pleistocene.

PL1216 Dam on A 'Marapana' property (Cole), Back Line Road, 2.7 km ENE of junction of Back Line (No. 11) and Wingaroo (No. 2A) roads, Memana, Flinders Island, Tasmania. AMG Flinders Island (Special) 926 799. Memana Formation, Plio-Pleistocene.

PL1217 Dam on B 'Marapana' property (Cole), Back Line Road, 2.7 km ENE of junction of Back Line (No. 11) and Wingaroo (No. 2A) roads, Memana, Flinders Island, Tasmania. AMG Flinders Island (Special) 927 797. Memana Formation, Plio-Pleistocene.

PL1218 Dam on Oakenfull's property, Back Line Road, 0.4 km N of junction of Back Line (No. 11) and Wingaroo (No. 2A) roads, Memana, Flinders Island. Tasmania. AMG Flinders Island (Special) 901 796. Memana Formation, Plio-Pleistocene.

PL1250 Dam on Lot 50, 'Bimbadeen' (Andrews), 1 km ESE of junction of Lackrana (No. 3) and Hauland Gap (No. 8) roads, Lackrana, Flinders Island. Tasmania. AMG Flinders Island (Special) 001 622. Cameron Inlet Formation.

PL1276 Dam on Lot 76 'Nangetty' (Mason), 1.6 km W of junction of Wingaroo (No. 2A) and Melrose (No. 2) roads, Memana, Flinders Island. Tasmania. AMG Flinders Island (Special) 903 762. Memana Formation. Some remanie shells from Cameron Inlet Formation.

PL1280 Dam on G. Smith's property, Back Line (No. 11) Road, 4 km SW of junction of Back Line (No. 11) and Wingaroo (No. 2A) roads, Memana, Flinders Island, Tasmania. AMG Flinders Island (Special) 872 761. Memana Formation, Plio-Pleistocene.

PL3003 Cove between Buckley Point and Point Pember, 4.5 km SE of Princetown, Victoria. AMG Princetown 896 106. Pebble Point Formation, Late Paleocene.

PL3010 Lower 6.5 m of cliff on S side of Blanche Point, Port Willunga, South Australia. AMG Noarlunga 689 963. Blanche Point Formation, Late Eocene, Aldingan.

PL3011 BCI, 9.6 m dark clay with Turritella below green sand in Washout 1 nearest mouth of Browns Creek, Johanna, Victoria. AMG Glenaire 079 058. Browns Creek Clay, Late Eocene, Aldingan.

PL3014 BCIV, dark gritty clay, in Washout 2, forked gully nearest mouth of Johanna River, Johanna, Victoria. AMG Glenaire 079 059. Browns Creek Clay, Late Eocene, Aldigan.

PL3015 Marl with bivales, above dark gritty clay in W (right) fork of Washout 2, forked gully nearest mouth of Johanna River, Johanna, Victoria. AMG Princetown 079 059. Browns Creek Clay, Late Eocene, Aldingan.

PL3016 G.S.V. loc. Aw5, 220 mm bed with smooth pectinids, lowest fossiliferous outcrop at W end of Castle Cove, Glenaire, Victoria. AMG Princetown 105 044. Browns Creek Clay, Late Eocene, Aldingan.

PL3020 G.S.V. loc. Aw4, Middle Beach, Aire Coast, clays beneath limestone, Victoria. AMG Princetown 121 030. Glenaire Clay.

PL3024 Cliff section opposite Bird Rock, below Bird Rock cap, Torquay, Victoria. AMG Torquay 642 518. Jan Juc Formation, Late Oligocene, Janjukian.

PL3025 Lower part of cliff, Fishermans Steps, 1.5 km SW of Bird Rock, Torquay, Victoria. AMG Inverleigh 632 506. Jan Juc Formation.

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PL3028 Lower bed in cliff between Fossil Bluff and 1.5 km NW towards Table Cape, Wynyard, Tasmania. AMG Table Cape 930 630. Freestone Cove Sandstone, Early Miocene, Longfordian.

PL3029 Upper (Turritella) bed in cliff between Fossil Bluff and 1.5 km NW towards Table Cape, Wynyard Tasmania. AMG Table Cape 930 630. Fossil Bluff Sandstone, Early Miocene, Longfordian.

PL3034 Surface material from slips on S bank of Lake Costin, 0.5 km W of Hordern Vale–Red Hill Road, Hordern Vale, Victoria. AMG Princetown 156 043. Fishing Point Marl, lower mollusc horizon, Early Miocene, Longfordian.

PL3035 Cliff section SE of Fischer's Point about 10 m above Lake Craven, Hordern Vale, Victoria. AMG Princetown 155 040. Fishing Point Marl, lower mollusc horizon, Early Miocene, Longfordian.

PL3036 Cliff 30 m above Lake Craven, 0.4 km NW of Red Hill, Hordern Vale, Victoria. AMG Princetown 156 030. Fishing Point Marl, lower mollusc horizon, Early Miocene, Longfordian.

PL3038 GSV Ad 14, shore platform 2.4 km N of Curlewis railway crossing, section 24, block 1, Parish of Moolap, Victoria. AMG Portarlington 823 733. Fyansford Formation, Early Miocene, Batesfordian.

PL3039 Shore platform, NE corner section 23, block 1, Parish of Moolap, Victoria. AMG Geelong 807 732. Fyansford Formation, Early Miocene, Batesfordian.

PL3040 Belmont shaft at 18 m at 'New Geelong' between Colac Road and Germantown Road, close to the latter, Victoria. Fyansford Formation, Early Miocene, Batesfordian. Shaft sunk about 1891, probably in Allot. 9, Parish of Barrarbool.

PL3041 G.S.V. loc. Fc20, bed 7, 20 m above flood plain, Amphitheatre, S of Bull Island, left bank of Yarrowee (Leigh) River, Victoria. AMG Ballarat 615 928. Fyansford Formation, Early Miocene, Batesfordian.

PL3048 Cutting on Boornong (= Steens) Road, 2.1 km N of Cooriemungle Road, Cooriemungle, Victoria. AMG Princetown 810 337. Gellibrand Marl, Early Miocene, Batesfordian.

PL3049 Cutting on SE side of Great Ocean Road, about 50 m NE of Serpentine (= Latrobe) Creek, Princetown, Victoria. AMG Princetown 872 149. Gellibrand Marl, Early Miocene, Batesfordian.

PL3054 At water level in left bank of Mitchell River, Skinners, SW corner of allotment 29A1, Parish of Wuk Wuk, Victoria. AMG Stratford 433 167. Wuk Wuk Marl, Early Miocene, Batesfordian.

PL3055 Cliff and shore platform on S side of Golf Course, Flinders, Victoria. AMG Western Port 268 387. Flinders Limestone, Early Miocene, Batesfordian.

PL3069 Cutting on Shelford–Inverleigh Road, Red Bluff, 4.8 km N of Hamilton Highway, Victoria. AMG Colac 616 847. Fyansford Formation, Middle Miocene, Balcombian.

PL3070 Cliff on left bank of Yarrowee (= Leigh) River at 'Farrells', Allotment 44, Parish of Carrah, Victoria. AMG Inverleigh 337 823. Fyansford Formation, Middle Miocene, Balcombian.

PL3071 0–5 m in cliff on left bank of Native Hut Creek, 1 km SW of Glenleigh, Victoria. AMG Inverleigh 454 816. Fyansford Formation, Middle Miocene, Balcombian.

PL3072 Approx. G.S.V. loc. Ad28, Orphanage Hill, Fyansford, Victoria. AMG Geelong 648 748. Fyansford Formation, Middle Miocene, Balcombian.

PL3074 18–20 m in caisson shaft of SE Trunk Sewer, NE corner of Boundary Road and Junction Road, Dingley, Victoria. Fyansford Formation, Middle Miocene, Balcombian.

PL3077 Altona Bay Coal Shaft No. 2 (1908), Victoria. Fyansford Formation, Middle Miocene, Balcombian.

PL3078 Shore platform at Fossil Beach, 3 km S of Mornington, Victoria. AMG Western Port 273 653. Fyansford Formation, Middle Miocene, Balcombian.

PL3082 Clifton Bank, Muddy Creek, 7 km W of Hamilton, Victoria. AMG Coleraine WD 818 225. Muddy Creek Formation, Middle Miocene, Balcombian.

PL3084 Small gully 4.8 km S of Morgan Ferry–Cadell Road on left bank of Murray River opposite Brenda Park Homestead, South Australia. AMG Morgan 790 280. Morgan Limestone, Cadell Marl Lens, Middle Miocene, Balcombian.

PL3093 0–10 ft above HWL, Rutledges Beach, E side of the mouth of Rutledge Creek, Victoria. AMG Princetown 783 209. Port Campbell Limestone, Rutledge Creek Member, Middle Miocene, Bairnsdalian.

PL3094 Notch at the Amphitheatre, mouth of Ingle Creek, Victoria. AMG Princetown 779 211. Port Campbell Limestone, Rutledge Creek Member, Middle Miocene, Bairnsdalian.

PL3095 G.S.V. Ad. 15, Western Beach, Corio Bay, Geelong, Victoria. AMG Inverleigh 682 754. Fyansford Formation, Middle Miocene, Bairnsdalian.

PL3097 0–2 m above water, cliff on left bank of Barwon River, Section 2b, Parish of Murgheboluc, Victoria. AMG Inverleigh 475 776. Fyansford Formation, Middle Miocene, Bairnsdalian.

PL3098 Right bank of Native Hut Creek, 100 m S of Hamilton Highway, Victoria. AMG Inverleigh 459 794. Fyansford Formation, Middle Miocene, Bairnsdalian.

PL3099 0–3 m above water, left banks of Native Hut Creek and Barwon River at junction, Victoria. AMG Inverleigh 462 788. Fyansford Formation, Middle Miocene, Bairnsdalian.

PL3100 0–3 m in the cliff on the left bank of Barwon River about 500 m downstream from junction with Bruces Creek, Section 4a, Parish of Murgheboluc, Victoria. AMG Inverleigh 503 770. Fyansford Formation, Middle Miocene, Bairnsdalian.

PL3101 Cliff, Moorpanyal Park, North Shore, Corio Bay, Geelong, Victoria. AMG Geelong 696 795. Fyansford Formation, Middle Miocene, Bairnsdalian.

PL3102 Bed of Warrambine Creek, immediately downstream from Winchelsea–Inverleigh Road bridge, Victoria. AMG Geelong 375 769. Fyansford Formation, Middle Miocene, Bairnsdalian.

PL3104 Cliff section S of Manyung Rocks and N of sewer pipe and jetty, Mt Eliza, Victoria. AMG Western Port 305 705. Fyansford Formation, Middle Miocene, Bairnsdalian. Bed 10B(a) of Gostin 1966.

PL3105 Quarry in Allotment 15, Section A, Parish of Moormurng, 400 m W of Pleasant Creek, Hillside, East Gippsland, Victoria. AMG Bairnsdale 455 136. Bairnsdale Limestone, Middle Miocene, Bairnsdalian.

PL3107 McCrae's Quarry, left bank of Toorloo Creek, Victoria. AMG Orbost 913 163. Bairnsdale Limestone, Middle Miocene, Bairnsdalian.

PL3108 Cliff just beneath Bairnsdale Limestone, left bank Mitchell River, SW corner of Allotment 15, Parish of Wy Yung (Drier's), Victoria. AMG Bairnsdale 501 145. Wuk Wuk Marl, Middle Miocene, Bairnsdalian.

PL3110 Large cutting on left bank of Tambo River, 200 m S of Princes Highway, Swan Reach, Victoria. AMG Bairnsdale 759 132. Tambo River Formation, Late Miocene, Mitchellian.

PL3114 Cutting on Princes Highway, beds 6a, b, lowest shell bed and nearest bridge, NE side of Bunga Creek, Victoria. AMG Orbost 911 100. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3115 Left bank of SE end of Lake Bunga near old trambridge (Lake Bunga Crossing), Victoria. AMG Orbost 918 085. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3116 Outcrop in road ditch, 20 m W of Lakes Entrance Development No. 1 oil bore, right bank of Bunga Creek, Victoria. AMG Orbost 912 096. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3117 Cutting, Princes Highway, NE side of Bunga Creek, second lowest shell bed nearest bridge (bed b), Victoria. AMG Orbost 911 100. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3118 Floor and sides of tramway cutting N of Scrivenors Road, Mississippi Creek, Victoria. AMG Colquhoun 835 114. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3119 Ritchies Cutting, Scrivenors Road, W side of Mississippi Creek, Victoria. AMG Colquhoun 835 114. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3120 Cutting N side of John Street, Lakes Entrance, E of small gully, SE corner of Allotment 30A, Section A, Parish of Colquhoun, Victoria. AMG Bairnsdale 869 075. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3122 Bluff on W side North Arm, Kalimna, S of Hunters Gully just above water level, Victoria. AMG Kalimna 865 074. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3123 Just below high tide level, E side of North Arm, on point below Ferndale Parade, Lakes Entrance, Victoria. AMG Kalimna 867 974. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3124 Bluff on W side of North Arm, N side of Hunters Gully, Lakes Entrance, 0–1 m above high water mark, Victoria. AMG Bairnsdale 864 077. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3125 Outcrop in road, 15.2 m above water, E bank North Arm opposite end of Hunters Road, Lakes Entrance, Victoria. AMG Bairnsdale 861 087. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3126 About 3 m above water on left bank of North Arm, below Nautilus Way, Lakes Entrance, Victoria. AMG Bairnsdale 867 080. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3127 Shells loose in soil in tramway cutting, Mississippi Creek near terminus at end of Comer Road, Victoria. AMG Colquhoun 852 103. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3131 Left bank Moorabool River, track on hillside about 300 m N of Moorabool Viaduct, Victoria. AMG Geelong 616 827. Moorabool Viaduct Sands, Late Miocene, Cheltenhamian.

PL3132 Bed of Spring Creek below tuff band, 800 m NE of Spring Creek Homestead, Minhamite, Victoria. AMG Minjah 248 927. Goodwood Formation, Late Miocene, Cheltenhamian, Late Miocene, Cheltenhamian.

PL3133 Left bank of River Murray at Wookool Bend about 3 m above water level, Loxton, South Australia. AMG Renmark VG 563 869. Bookpurnong Beds, Late Miocene, Cheltenhamian.

PL3137 Forsyths Bank, left bank of Grange Burn about 1 m above water level, Victoria. AMG Coleraine WD 832 237. Grange Burn Formation, Early Pliocene, Kalimnan.

PL3138 Bed of Grange Burn at the E end of 'Porphry Gorge' by the 'rock stack', Victoria. AMG Coleraine WD 837 235. Grange Burn Formation, Early Pliocene, Kalimnan.

PL3139 Bed of Muddy Creek at McDonalds Bank, Yulecart, Victoria. AMG Coleraine WD 826 219. Grange Burn Formation, Early Pliocene, Kalimnan.

Appendix continued overleaf

PL3140 Cutting on Princes Highway, bed 6d, NE side of Bunga Creek, Victoria. AMG Orbost 912 102. Jemmys Point Formation, Early Pliocene, Kalimnan.

PL3141 Cutting on Princes Highway, SW side of Bunga Creek, bed 5c, upper Jemmys Point shell bed, Victoria. AMG Orbost 907 097. Jemmys Point Formation, Early Pliocene, Kalimnan.

PL3147 G.S.V. loc. F7, shell bed in cliff behind Nyerimalang Jetty, about 3 m above high tide, Victoria. AMG Bairnsdale 816 072. Jemmys Point Formation, Early Pliocene, Kalimnan.

PL3148 0–4 m above high water mark in cliff E of Kalimna Jetty, Kalimna, Victoria. AMG Bairnsdale 840 070. Jemmys Point Formation, Early Pliocene, Kalimnan. Lower shell bed at Jemmys Point.

PL3149 Shell band exposed in cutting on Princes Highway, Jemmys Point, Victoria. AMG Bairnsdale 850 068. Jemmys Point Formation, Early Pliocene, Kalimnan.

PL3150 Shell band about 7 m above high water mark in cliff on E side of Hopkins Bight, Nungurner, Victoria. AMG Bairnsdale 789 069. Jemmys Point Formation, Early Pliocene, Kalimnan.

PL3151 Large cutting on Nyerimalang Estates Road, on right bank of Meringa Creek about 200 m S of Kalimna Nungurner Road, Victoria. AMG Colquhoun 825 077. Jemmys Point Formation, Early Pliocene, Kalimnan.

PL3153 Bed of Minnie Creek, Allotment 27, Parish of Myaring, Victoria. AMG Dartmoor WD 218 178. Whalers Bluff Formation, Late Pliocene, Werrikooian.

PL3155 Pecten bed in grey sand, quarry on E side of McKinnon Road, about 1 km N of Myaring Bridge Road, Victoria. AMG Dartmoor WD 220 208. Whalers Bluff Formation, Crawford Member, Early Pleistocene, Werrikooian.

PL3161 Pit on S side of Runymede Road, about 3 km E of Runymede Station, Sandford, Victoria. AMG Casterton 370 304. Sandford Limestone, Early Miocene, Longfordian.

PL3163 Cutting on Williams Road, 0.6 km E of Boomong Road junction, Cowleys Creek, Victoria. AMG Corangamite XC 815 374. Gellibrand Marl, Early Miocene, Batesfordian.

PL3165 Large Main Road Department quarry, 16 km S of Madura Roadhouse, Roe Plain, Western Australia. AMG Burnabbie 1:250 000 sheet grid ref. 315 643. Roe Calcarenite, Pliocene.

PL3167 Pit 1.6 km N of Hampton Microwave Repeater Tower, Roe Plain, Western Australia. AMG Eucla 1:250 000 sheet grid ref. 365 464. Roe Calcarenite, Pliocene.

PL3172 Spoil from 10 m foundation holes for Hampton Microwave Repeater Tower, 53 km E of Madura and 6.3 km S of Eyre Highway, Roe Plain. (site 33) Western Australia. AMG Eucla 1:250 000 sheet CK 365 462. Roe Calcarenite, Pliocene.

PL3174 Nelson's lime quarry, Devils Hole Track, 2 km W of its junction with Lake Tyers House Road, Victoria. AMG Hospital Creek (1:25 000) 996 202. Bairnsdale Limestone, Middle Miocene, Bairnsdalian.

PL3175 Cliff section on E side of Nowa Nowa Arm of Lake Tyers just S of Camerons Arm, about 200 m N of car park at end of Camerons Arm No. 2 Track, Victoria. AMG Hospital Creek (1:25 000) 999 174. Bairnsdale Limestone, Middle Miocene, Bairnsdalian.

PL3179 Left bank Murray River about 2 m above river in low cutting at N end of Fred's Landing Reserve about 3 km S of Tailem Bend, South Australia. AMG Wellington 593 945. Norwest Bend Formation, Pliocene.

PL3180 Left bank Murray River just below Sunnyside Lookout, Burdett, South Australia. AMG Mobilong 516 209. Mannum Formation, Early Miocene, Longfordian.

PL3181 Cutting on Mannum–Murray Bridge Road on S side of Reedy Creek about 0.5 km E of bridge, 7 km SE of Mannum, South Australia. AMG Tepko 385 316. Mannum Formation, Early Miocene, Longfordian.

PL3182 Limestone sitting on granite in quarry reserve, Section 156, Hundred of Younghusband, Taworri, 5 km NE of Mannum, South Australia. AMG Mannum 493 373. Mannum Formation, Early Miocene, Longfordian.

PL3183 Cutting on Baker's Hut Road about 200 m S of East Front Road (Riverside Drive), just E of Tarawwa, South Australia. AMG Mannum 497 375. Mannum Formation, Early Miocene, Longfordian.

PL3184 Large benched quarry on East Front Road, 1 km NE of Taworri, 5.3 km NE of Mannum ferry landing, South Australia. AMG Mannum 507 380. Mannum Formation, Early Miocene, Longfordian.

PL3185 Large cutting on Panorama Avenue, Younghusband about 200 m S of East Front Road, about 15 km NE of Mannum, South Australia. AMG Mannum 603 400. Mannum Formation, Early Miocene, Longfordian.

PL3186 Quarry opposite Kia Marina, Kia, 9.5 km NE of Mannum, opposite Pellaring Flat, South Australia. AMG Mannum 527 396. Mannum Formation, Early Miocene, Longfordian.

PL3187 Left bank of Murray River; 'Younghusband' quarry on S side of 'Riverside Drive', 300 m W of Canoe tree and 21.4 km E of Mannum ferry crossing, South Australia. AMG Caurnamont 651 392. Mannum Formation, Early Miocene, Longfordian.

PL3188 Lower part of excavation behind toilets in Mannum Pumping Station Reserve, Mannum, South Australia. AMG Mannum 453 344. Mannum Formation, Early Miocene, Longfordian.

PL3189 Limestone above clay in cutting on access road to Mannum Pumping Station Reserve, Mannum, South Australia. AMG Mannum 452 343. Morgan Limestone, Middle Miocene, Balcombian.

PL3190 Cutting on Underwood Hill Road, 300 m W of intersection with Mannum–Purnong Road, 6 km NE of Mannum on right bank of Murray River, South Australia. AMG Mannum 496 390. Mannum Formation, Early Miocene, Longfordian.

PL3191 Cutting on Klose Road, about 400 m N of intersection with Mannum–Purnong Road, 6 km NE of Mannum, South Australia. AMG Mannum 499 395. Mannum Formation, Early Miocene, Longfordian.

PL3192 Low cutting on Mannum–Sedan Road, 100 m S of Eichler and Stockwell roads junction, Punthari, South Australia. AMG Mannum 452 457. Mannum Formation, Early Miocene, Longfordian.

PL3193 Right bank of River Murray S of mouth of River Marne; cutting on side of road down hill to houses at Wongulla, South Australia. AMG Swan Reach 685 584. Mannum Formation, Early Miocene, Longfordian.

PL3194 Cliff on left bank of Murray River just S of Walker Flat Ferry, Walker Flat, South Australia. AMG Caurnamont 692 530. Mannum Formation, Early Miocene, Longfordian.

PL3195 Cliff on left bank of Murray River just N of ferry at Swan Reach, South Australia. AMG Swan Reach 715 743. Mannum Formation, Early Miocene, Longfordian.

PL3196 Cliff on left bank Murray River N end of Big Bend Reserve, Section 64, Hundred of Nildottie, 7 km NNW of Nildottie, South Australia. AMG Swan Reach 727 670. Mannum Formation, Early Miocene, Longfordian.

PL3197 Cliff left bank Murray River, N of Greenways Landing, Nildottie, about 20 m above river level, South Australia. AMG Swan Reach 773 646. Morgan Limestone?, Middle Miocene, Balcombian?.

PL3198 Cutting on approach to bridge at Blanchetown on W side (right bank) of Murray River, South Australia. AMG Blanchetown 723 984. Morgan Limestone, Middle Miocene, Balcombian.

PL3199 Cliff on left bank Murray River, 10 m above river, 10 km N of Swan Reach, NW of 'Cooinda', South Australia. AMG Blanchetown 706 830. Mannum Formation, Early Miocene, Longfordian.

PL3200 Cliff on left bank of Murray River about 2.5 km S of Moorundie, South Australia. AMG Blanchetown 727 910. Morgan Limestone, Middle Miocene, Balcombian.

PL3201 Cliff at base of Blanchetown Bridge on right bank Murray River, about 2 m above water level, South Australia. AMG Blanchetown 724 985. Mannum Formation, Early Miocene, Longfordian.

PL3202 Excavation in gully in middle of Blanchetown, W side of Adams Street, South Australia. AMG Blanchetown 725 976. Morgan Limestone, Middle Miocene, Balcombian.

PL3203 Cliff left bank Murray River about 10 m above lagoon at South Australian Water Ski Association facility, 7 km NNE of Blanchetown, South Australia. AMG Blanchetown 753 044. Morgan Limestone, Middle Miocene, Balcombian.

PL3205 Cliff left bank Murray River below ruin of Woods Flat Post Office, 2 km S of 'Carinya', 13 km N of Blanchetown, South Australia. AMG Morgan 750 109. Morgan Limestone, Middle Miocene, Balcombian.

PL3206 Cliff on right bank of Murray River at Bryants Creek Reserve, about 3 km NE of Morgan and just upstream from Morgan–Whyalla Pumping Station Reserve, South Australia. AMG Morgan 794 347. Morgan Limestone, Middle Miocene, Balcombian.

PL3208 Cliff left bank Murray River on Great Yarra Reach, about 30 m above water level, 11 km E of Waikerie, South Australia. AMG Pooginook 172 168. Morgan Limestone, Middle Miocene, Balcombian.

PL3209 Cliff on left bank Murray River at Good Hope Landing, 14 km E of Waikerie, South Australia. AMG Pooginook 207 181. Mannum Formation, Early Miocene, Longfordian.

PL3210 Cliff on left bank Murray River at Woolpunda Pumping Station, 21 km E of Waikerie, South Australia. AMG Pooginook 277 179. Mannum Formation, Early Miocene, Longfordian.

PL3211 Cliff on left bank Murray River on 'Karelia' road just above house, 6.5 km NW of Kingston, South Australia. AMG Overland Corner 350 167. Morgan Limestone, Middle Miocene, Balcombian.

PL3212 Cliff on right bank of Murray River at 'Cave Cliff', 8.5 km SW of Overland Corner, 10 m above water level, South Australia. AMG Pooginook 305 185. Mannum Formation, Early Miocene, Longfordian.

PL3213 Cliff at Pumping Station at Ramco Point, left bank Murray River, South Australia. AMG Cadell 998 207. Pata Limestone, Middle Miocene, Bairnsdalian.

PL3214 Cliff left bank Murray River, 3.5 km SE of Cadell, South Australia. AMG Cadell 883 311. Morgan Limestone, Middle Miocene, Balcombian.

PL3215 Cliff right bank Murray River at 'Nikalepko' Station, 4.5 km E of Cadell, South Australia. AMG Cadell 905 324. Morgan Limestone, Middle Miocene, Balcombian.

PL3217 Top of cliff right bank Murray River on 'Yarra View', about 7 km due E of Waikerie, South Australia. AMG Pooginook 136 178. Morgan Limestone, Middle Miocene, Balcombian.

Appendix continued overleaf

PL3218 Base of cliff right bank Murray River on 'Yarra Glen', about 16 km E of Waikerie, South Australia. AMG Pooginook 228 201. Mannum Formation, Early Miocene, Longfordian.

PL3219 Quarry on E side of Nelson North Road, about 0.2 km N of Huebners Road, Nelson, Victoria. AMG Oxbow Lake 006 903. Gambier Limestone, Early Miocene, Longfordian.

PL3220 Low cliff on right bank of Glenelg River, immediately below Mount Gambier Road bridge, Nelson, Victoria. AMG Oxbow Lake 003 887. Gambier Limestone, Early Miocene, Longfordian.

PL3221 Cliff either side of the mouth of Dry Creek near Donovans Landing, South Australia. AMG Gambier 969 947. Gambier Limestone, Early Miocene, Longfordian.

PL3222 Quarry about 0.5 km W of Victorian–South Australian border, 1.5 km NNW of mouth of Dry Creek, South Australia. AMG Gambier 965 960. Gambier Limestone, Early Miocene, Longfordian.

PL3223 Quarry about 0.5 km W of Border Road, about 1 km SW of 'Honeysuckle', Victoria. AMG Gambier 966 972. Gambier Limestone, Early Miocene, Longfordian.

PL3224 Quarry in corner of paddock WNW of ruin, 0.4 km N of Dry Creek valley, South Australia. AMG Gambier 957 965. Gambier Limestone, Early Miocene, Longfordian.

PL3225 Quarry between Bonds Road and Dry Creek Road, 1.5 km S of 'Honeysuckle', Victoria. AMG Gambier 975 965. Gambier Limestone, Early Miocene, Longfordian.

PL3226 Fallen block from 3 m above water, right bank of Glenelg River at Donovans, South Australia. AMG Gambier 966 925. Gambier Limestone, Early Miocene, Longfordian.

PL3227 Cliff about entrance to Amphitheatre Cave, right bank Glenelg River, Victoria. AMG Gambier 986 954. Gambier Limestone, Early Miocene, Longfordian.

PL3228 Cliff section at a fissure on right bank of Glenelg River, between Dry Creek and Reed Bed, South Australia. AMG Gambier 966 943. Gambier Limestone, Early Miocene, Longfordian.

PL3230 ACI Lime Quarry, 3.6 km WSW of Donovans Landing, South Australia. AMG Gambier 927 918. Gambier Limestone, Early Miocene, Longfordian.

PL3231 Quarry N side of Donovans Road, about 1 km SW of 'Summer Hill', 2.6 km W of Donovans Landing, South Australia. AMG Gambier 937 929. Gambier Limestone, Early Miocene, Longfordian.

PL3232 Quarry on N side of Galpins Road, 0.2 km E of intersection with Cox and Tervorft roads, South Australia. AMG Gambier 821 919. Gambier Limestone, Early Miocene, Longfordian.

PL3233 Quarry on W side of Tervorft Road, 0.2 km N of junction with Galpins Road, South Australia. AMG Gambier 817 920. Gambier Limestone, Early Miocene, Longfordian.

PL3234 Pit about 400 m N of Earls Cave East Road, about 0.5 km E of Earls Cave Road, South Australia. AMG Gambier 802 930. Gambier Limestone, Early Miocene, Longfordian.

PL3235 Gambier Earth Movers Pty Ltd quarry, Loudin Hill Road, approx. 150 m S of intersection with Port McDonnell Road, 6.7 km SSW of Mount Gambier P.O., South Australia. AMG Gambier 785 066. Gambier Limestone, Early Miocene, Longfordian. Also known as Telford Quarry.

PL3236 Pit on S side of McLeans Road, about 0.5 km W of Port MacDonell Road, South Australia. AMG Schank 745 003. Gambier Limestone, Early Miocene, Batesfordian.

PL3237 Ron Butler's cut stone quarry, Section 134, Hundred of Blanche, on S side of Mitchell Road, South Australia. Gambier Limestone, Late Oligocene, Janjukian.

PL3238 Commercial Minerals Ltd cut stone quarry, NE corner of McNamara and Cafpirco roads, Marte, South Australia. AMG Schank 683 145. Gambier Limestone, Late Oligocene, Janjukian.

PL3239 Quarry at SE corner of Tolmie Street and Penola Road, 0.8 km NE of Princes Highway, South Australia. AMG Gambier 813 143. Gambier Limestone, Early Miocene, Longfordian.

PL3240 Pit 0.4 km S of Settlers Road and 1 km W of Ellis Road, South Australia. AMG Gambier 785 968. Gambier Limestone, Early Miocene, Longfordian.

PL3241 Spoil from fish ponds on Telford's fish farm, N side of Telfords Road, 0.8 km E of Ellis Road, South Australia. AMG Gambier 800 960. Gambier Limestone, Early Miocene, Longfordian.

PL3242 Pit on Telford's fish farm about 200 m N of Telfords Road and about 200 m E of house, 1.2 km E of Ellis Road, South Australia. AMG Gambier 805 958. Gambier Limestone, Early Miocene, Longfordian.

PL3244 Council quarry on I. N. and C. J. Smith's property, 0.3 km W of Smiths Road and 1.6 km S of Kingsley Road, South Australia. AMG Schank 700 923. Gambier Limestone, Early Miocene, Longfordian.

PL3245 Quarry on W side of Comaum Forest Road, 3.8 km NE of Penola–Naracoorte Road, South Australia. AMG Struan 903 830. Naracoorte Limestone, Early Miocene, Longfordian.

PL3246 Elderslee Quarry, Elderslee–Cromper Road, about 2.5 km SE of Naracoorte, South Australia. AMG Hynam 791 090. Naracoorte Limestone, Early Miocene, Longfordian.

PL3247 James Quarry, S side Edenhope Road, 1.6 km E of Naracoorte, South Australia. AMG Hynam 788 102. Naracoorte Limestone, Early Miocene, Longfordian.

PL3248 Henske's Quarry, Blackwell Road, 2.6 km SE of Naracoorte, South Australia. AMG Hynam 793 085. Naracoorte Limestone, Early Miocene, Longfordian.

PL3250 Calcimo Lime & Fertiliser Pty Ltd quarry, left bank of Merriman Creek, Stradbroke West, Victoria. AMG Stradbroke West 947 639. Gippsland Limestone, Early Miocene, Longfordian.

PL3251 Old Australian (Gippsland) Cement quarry, left bank of Merriman Creek, 21 km ESE of Rosedale at end of Rosedale–Stradbroke Road, Victoria. AMG Stradbroke West 1:25 000 DT 952 652 (quarry centre DT 955 655). Gippsland Limestone, Early Miocene, Longfordian. Quarry now (1996) mostly revegitated.

PL3252 Glencoe (= Brock's) Lime Quarry, N side of Longford–Dutson Road, 4 km E of Longford, Victoria. AMG Dutson 1:25 000 ET 111 744. Glencoe Limestone Member, Gippsland Limestone, Early Miocene, Longfordian.

PL3253 McColl's Quarry, right bank of Boundary Creek, Victoria. AMG Dutson 146 734. Gippsland Limestone, Early Miocene, Longfordian.

PL3254 'Gippsland Cement' Quarry, right bank of Boggy Creek, approx. 2.7 km SSW of Longford, W side of South Gippsland Highway, Victoria. AMG Longford 1:25 000 ET 065 738. Gippsland Limestone, Early Miocene, Longfordian.

PL3255 Darriman Lime Quarry on Morris Creek, Victoria. AMG Darriman 916 424. Gippsland Limestone, Early Miocene, Longfordian.

PL3256 Top of cutting on track to flat on 'Myrtle Point', left bank Mitchell River, 2 km SE of Calulu, Victoria. AMG Wy Yung 466 158. Bairnsdale Limestone, Middle Miocene, Bairnsdalian.

PL3257 Cutting on track down to flat on N. and M. Schaeche property, west of Dockerty Lane, Wy Yung, Victoria. AMG Wy Yung 504 142. Bairnsdale Limestone, Middle Miocene, Bairnsdalian.

PL3258 Lime pit at end of Dooley Street, Wy Yung, Victoria. AMG Wy Yung 533 157. Bairnsdale Limestone, Middle Miocene, Bairnsdalian.

PL3259 Cutting on left bank of Toorloo Arm of Lake Tyers on approach to Burnt Bridge, Victoria. AMG Cunninghame 932 145. Tambo River Formation, Late Miocene, Mitchellian.

PL3260 Right bank of Toorloo Arm of Lake Tyers, about 1 m above water level, 0.4 km S of Burnt Bridge Road bridge, Victoria. AMG Cunninghame 933 141. Tambo River Formation?, Late Miocene, Mitchellian? Same as PL3109.

PL3261 2–3 m below track on N side of Long Point Track, Toorloo Arm, 0.5 km W of end of Long Point, Victoria. AMG Cunninghame 934 134. Tambo River Formation, Late Miocene, Mitchellian.

PL3262 Just above water level on W side of Toorloo Arm of Lake Tyers, 0.5 km SE of end of Long Point, Victoria. AMG Cunninghame 941 126. Tambo River Formation, Late Miocene, Mitchellian.

PL3263 Wombat hole on W side of Toorloo Arm of Lake Tyers, about 2 m above water, 0.3 km SE of Long Point, Victoria. AMG Cunninghame 940 132. Tambo River Formation, Late Miocene, Mitchellian.

PL3265 Shore opposite Mill Point boat ramp, Victoria. AMG Cunninghame 946 122. Jemmys Point Formation?, Late Miocene, Cheltenhamian?

PL3266 Small bay on left bank of Toorloo Arm of Lake Tyers, due E of Long Point, Victoria. AMG Cunninghame 942 134. Tambo River Formation, Late Miocene, Mitchellian.

PL3267 East bank of Nowa Nowa Arm of Lake Tyers on W point of peninsula due W of Reedy Arm, Victoria. AMG Hospital Creek 994 159. Tambo River Formation, Late Miocene, Mitchellian.

PL3269 Point on Trident Arm of Lake Tyers between northern and middle arms opposite Ironbark Track picnic area, Victoria. AMG Hospital Creek 996 202. Tambo River Formation, Late Miocene, Mitchellian. Nodule bed on shore platform

PL3270 Shells from slope 0–5 m above water SW of end of Ironbark Track, Lake Tyers, Victoria. AMG Hospital Creek 000 134. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3271 About 300 m NE of end of Morgans Landing Track, NE of island at end of track, left bank Nowa Nowa Arm of Lake Tyers, Victoria. AMG Hospital Creek 996 144. Jemmys Point Formation, Late Miocene, Cheltenhamian.

PL3272 Cliff below camping reserve at end of southern branch of Trident Arm Track, E bank of Nowa Nowa Arm of Lake Tyers, Victoria. AMG Hospital Creek 997 130. Jemmys Point Formation, Early Pliocene, Kalimnan.

PL3273 Railway cutting 300 m W of bridge over old Princes Highway, Victoria. AMG Orbost 260 234. Gippsland Limestone, Middle Miocene, Bairnsdalian.

PL3274 Western end of S side of Godsells Point, S of Hunter Gully about 10 m above water, Victoria. AMG Kalimna 862 074. Jemmys Point Formation, Early Pliocene, Kalimnan.

PL3275 End of Godsells Point, S of Hunter Gully, about 5 m above water, W side of North Arm, Victoria. AMG Kalimna 864 074. Jemmys Point Formation, Early Pliocene, Kalimnan.

PL3276 Low on cliff at Devils Backbone, right bank Snowy River at Lochend, Victoria. AMG Marlo 346 197. Bairnsdale Limestone, Middle Miocene, Bairnsdalian.

Appendix continued overleaf

PL3277 Low in cliff section on N side of Point Addis, Victoria. AMG Point Addis 600 469. Point Addis Limestone, Late Oligocene, Janjukian.

PL3278 Blue Circle Southern Cement Ltd quarry, Reservoir Road, eastern pit near Anglesea Road, Victoria. AMG Geelong 620 665. Waurn Ponds Limestone, Late Oligocene, Janjukian.

PL3279 Blue Circle Southern Cement Ltd quarry, Reservoir Road, western (old) pit 0.7 km S of Princes Highway, Victoria. AMG Geelong 600 665. Waurn Ponds Limestone, Late Oligocene, Janjukian.

PL3280 North and S sides of cutting about 0.25 km W of Myaring Bridge on Myaring–Pieracle Road, about 100 m from Grubbed Road, Victoria. AMG Casterton 197 195. Whalers Bluff Formation, Late Pliocene, Werrikooian.

PL3281 Thin lense on top of Mannum Formation in borrow pit on S side of Lagoon Road, about 0.7 km W of Murray Bridge–Ponde Road, South Australia. AMG Mobilong 515 222. Norwest Bend Formation, Pliocene.

PL3282 Low in cliffs between Rogue Point and Sliding Rock, S of Ardrossan, South Australia. AMG Port Julia 650 776. Muloowurtie Formation, Late Eocene, Aldingan.

PL3283 About 1 m above Port Julia Greensand, about 200 m S of Port Julia Jetty, South Australia. AMG Port Julia 636 600. Rogue Formation, Late Eocene, Aldingan.

PL3284 At beach level in cliff about 1 km S of Port Julia Jetty near shacks, South Australia. AMG Port Julia 635 590. Rogue Formation, Late Eocene, Aldingan.

PL3285 Base of cliffs immediately N of Dowcer Bluff, 2.5 km N of Port Vincent, South Australia. AMG Stansbury 623 508. Rogue Formation, Late Eocene, Aldingan.

PL3286 Building excavation into low cliff on corner of Young Avenue and Esplanade, Port Vincent, South Australia. AMG Stansbury 610 466. Port Willunga Formation, Late Oligocene, Janjukian.

PL3287 About 10 m above beach in cliff about 100 to 250 m S of Port Vincent, South Australia. AMG Stansbury 609 462. Port Willunga Formation, Late Oligocene, Janjukian.

PL3288 Adelaide Brighton Cement Holdings Ltd quarry at Kleins Point, 5 km S of Stansbury, Yorke Peninsula, South Australia. AMG Stansbury 530 280. Port Willunga Formation, Late Oligocene, Janjukian.

PL3290 Boulders below Point Turton limestone quarry, about 100 m W of jetty, South Australia. AMG Turton 145 318. Point Turton Limestone, Late Oligocene, Janjukian.

PL3291 Shell bed and oyster bed at base of cliff about 300 m N of boat ramp at Giles Point, South Australia. AMG Edithburgh 521 194. Hallett Cove Sandstone, Pliocene.

PL3292 Cliffs about 300–500 m S of Wool Bay jetty, South Australia. AMG Edithburgh 515 234. Port Willunga Formation, Late Oligocene, Janjukian.

PL3293 Quarry and cliffs 100–200 m N of Stansbury jetty, South Australia. AMG Stansbury 554 344. Port Willunga Formation, Late Oligocene, Janjukian.

PL3295 Bryozoal limestone sitting on Archaean at Myponie Point, South Australia. AMG Wallaroo 665 191. Melton Limestone, Early Miocene, Longfordian.

PL3296 Gritty limestone at base of cliff 0.2 km N of Black Rock, South Australia. AMG Wallaroo 687 207. Melton Limestone, Early Miocene, Longfordian.

PL3297 Between tide levels on left bank of Onkaparinga River between footbridge and mouth of river, South Australia. AMG Noarlunga 696 058. Port Willunga Formation, Late Eocene, Aldingan.

PL3299 Abattoirs Bore, South Australia. Dry Creek Sands, Middle Miocene.

PL3467 Upper part of cliffs S of Port Willunga jetty, South Australia. AMG Yankalilla 685 945. Hallett Cove Sandstone, Pliocene.

PL3524 General locality reference for Batesford, at or in the vicinity of the Australian Cement Ltd quarry, Victoria. Batesford Limestone, Early Miocene, Batesfordian.

PL3552 Old Kawarren Quarry on N side of Loves Creek, Kawarren, 15 km S of Colac, Victoria. Clifton Formation?, Late Oligocene, Janjukian.

PL3554 Cliff at Yellow Bluff, Torquay, Victoria. AMG Torquay 1:25 000 BT 663 539. Puebla Formation.

PL3555 Low foreshore cliffs at Point Danger, Victoria. AMG Torquay 1:25 000 BT 663 529. Puebla Formation, Zeally Limestone Member.

PL3559 Vicinity of Rocky Point (Jan Juc Point), just S of the mouth of Spring Creek Victoria. Puebla Formation, Zeally Limestone Member.

PL3582 Upper part of Abrakurrie Cave, N of Eyre Highway about 35 km W of Eucla, Western Australia. Abrakurrie Limestone.

PL3583 Upper most 60 ft (18 m) of Wilson Bluff Limestone in Abrakurrie Cave, N of Eyre Highway about 35 km W of Eucla, Western Australia. Wilson Bluff Limestone.

PL3584 About 40 ft (12 m) below level of plain in Toolina Cave, S of Eyre Highway near coast, about 135 km ESE of Balladonia, Western Australia. Toolina Limestone.

PL3596 About 76 m in House Bore, Angus Home, Salisbury, South Australia. Dry Creek Sands, Late Miocene. Drilled by J. J. Preiss & Son.

PL3597 Bore 17-2-525 3878 01, depth 103 m, on 'Sylvan Glade', R. V. Stephens, South Australia. AMG Gawler 850 642 approx. Port Willunga Formation, Early Miocene. Drilled 1968 by Olympus Boring Contractors.

PL3598 Bore 593-5024-14, 82–84 m, Waterloo Corner, South Australia. Dry Creek Sands, Late Miocene. Drilled by J. J. Preiss & Son, March 1971.

PL3599 Base of sandstone at southern end of amphitheatre, Hallett Cove, South Australia. AMG Noarlunga 717 154. Hallett Cove Sandstone, Pliocene.

PL3600 Upper part of cliff at Blanche Point, Aldinga Bay, Port Willunga, South Australia. AMG Noarlunga 689 963. Hallett Cove Sandstone, Pliocene.

PL3611 500–550 ft in bore at Royal Adelaide Golf Course bore, Tapleys Hill Road, Seaton, South Australia. Dry Creek Sands, Late Miocene. Drilled 1969.

PL3612 80 ft in bore 240, Section 261, Hundred of Yatala (G. Heading), Klemzig, South Australia. Blanche Point Formation, Late Eocene, Aldingan.

PL3613 Left bank Murray River at water level at base of cliff SW of Loxton Caravan Park, South Australia. AMG Loxton 583 873. Bookpurnong Beds.

PL3614 'Fossil Quarry, right bank Murray River, off Blanchetown Road, 2.3 km S of Blanchetown. South Australia. AMG Morgan 765 310. Norwest Bend Formation.

PL3615 Large road cutting 0.3 km S of East Front Road, 15 km NE of Mannum, South Australia. AMG Mannum 617 393. Mannum Formation.

PL3616 Shallow quarry on East Front Road, 7.5 km NE of Mannum, South Australia. AMG Mannum 565 406. Mannum Formation.

PL3617 Coastal cliff S of Muloowurtie Point, southernmost outcrop with pectinids, 4 km SW of Rogues Point, South Australia. AMG Point Julia 647 754. Muloowurtie Formation.

PL3618 Base of low cliff extending from below Onkaparinga Trig to about 200 m S, Port Noarlunga South. South Australia. AMG Noarlunga 690 048. Port Willunga Formation.

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TRANSACTIONS

OF THE

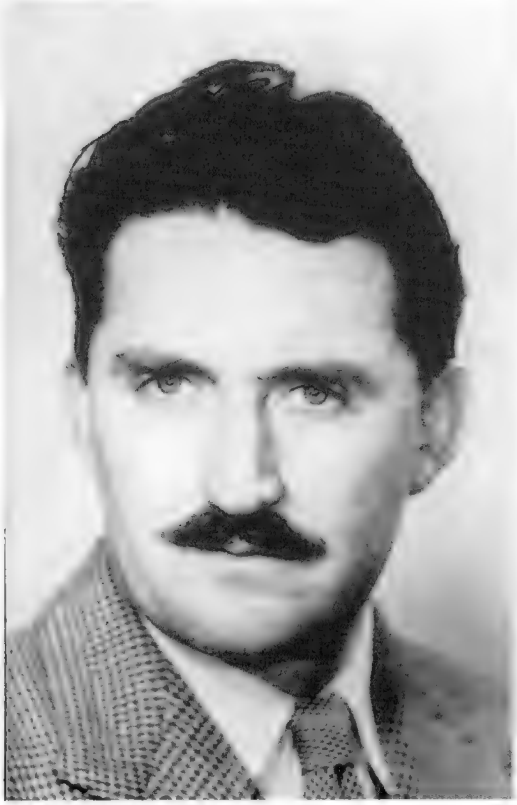
ROYAL SOCIETY OF VICTORIA

OBITUARY—G. A. THOMAS

GEORGE ANTHONY THOMAS
30 June 1921–13 November 2000

George Anthony Thomas passed away on the 13th day of November 2000, having successfully undergone surgery a few days previously. George had a broad appreciation of the breadth of Science and joined the Royal Society of Victoria in 1944. He became a Life Member in 1985. During his career he contributed two articles to the *Proceedings* of the Society. The *Proceedings* were an important part of his library and were read with great interest. He had a great respect for, and knowledge of, the natural world and specialised in his career on palaeontology and field geology.

George was born in Northcote (Melbourne) in 1921. He was the eldest of six children (sisters Shirley, Valda and Patricia, and brothers Kenneth and Warren) born to his father, George, and his mother, Dorothy (*nee* McMahon). The family lived in Clifton Hill. George's interest in nature, in particular geology, began with his childhood rambles, complete with dogs in tow, up and down the banks of the Merri Creek. He was quick to notice the massive layers of (Quaternary) basalt overlying the obviously different older (Silurian) rocks beneath.



George Thomas *c.* 1952

George Thomas 1999

He attended St John's Primary School, Clifton Hill and St Thomas's Christian Brothers Secondary School, Fitzroy, before achieving a place at St Kevin's College in Toorak to undertake his Leaving Certificate. However, the aftermath of the Great Depression was still widely felt throughout the community and George, well aware of the scarcity of the necessities of life and his parent's position, left school to work as a copyboy for *The Herald* newspaper. Nevertheless, George never gave up his love of reading, learning and science, and he enrolled part time at the Austral College in Collins Street (Melbourne) in order to complete his

Matriculation Certificate. He was later to take up a junior position at the National Museum of Victoria.

In 1940, George gained a place at the University of Melbourne where he commenced a science degree with major studies in Geology and Zoology. On 16 June 1945, during the King's Birthday weekend, he married a fellow geology student, Nancy Mary Fenwick-Barbour, at St Patrick's Cathedral, East Melbourne (then Nancy's Parish Church).

This was the time of the Second World War and, as a student, George was a corporal in the Melbourne University Rifles. His father, a veteran of the First World War's Western Front, advised George that an officer's life was preferable. The National Museum of Victoria had a use for George until 1944 when he enlisted in the Royal Australian Air Force as Pilot Officer George Thomas. With his background in Geology, he was drawn into the new area of Operational Research on such tasks as air photo interpretation. He then took part in the Allied invasion of the island of Borneo.

After the War, new opportunities in Geology resulted in George joining the Commonwealth Bureau of Mineral Resources (BMR), Geology and Geophysics in 1948. George, Nancy and new daughter Marianne moved to Canberra in 1949 and son Paul was born in 1951.

On joining the BMR, George commenced field work in the Carnarvon Basin, Western Australia, under the leadership of Curt Teichert for 'a couple of weeks'. The 'couple of weeks' became five months! Communications were limited in such a remote region and so it was that George and half the Western Australian outback heard the news of Marianne's first tooth—courtesy of the Royal Flying Doctor's radio network.

George further developed his interests in palaeontology during the BMR field seasons of the late 1940s and 1950s in the Carnarvon, Canning and Bonaparte basins of Western Australia. In particular, fossil brachiopods from the Devonian to Permian were to capture his imagination. He enrolled for a PhD at the University of Melbourne and spent time at the University in the mid 1950s, graduating in 1961. He joined the staff of the Department of Geology at the University of Melbourne in 1960 and was a Senior Lecturer in that department until his retirement.

In 1960, George, Nancy and family returned from Canberra to live in North Melbourne and then Ivanhoe. The family continued to grow with the arrival of Peter and then Michael and Andrew.

George's geological career was to commence with extensive field work and mapping in the Carnarvon, Canning and Bonaparte basins of western and northern Australia. This field work was to supply many of the specimens that were to become critical in George's studies on Late Palaeozoic brachiopods of Western Australia. In addition to the meticulous mapping of rock outcrops, palaeontological studies were seen by George as being essential to the correct determination of the ages of the Late Palaeozoic sequences. Hence, significant discoveries by George included the proving on palaeontological grounds of the existence of an Early Carboniferous succession in the Canning Basin (Thomas 1955b, 1957a) and the palaeontological proof of a Late Permian Tatarian (or Wuchiapingian in current terms) succession in both the Canning and Bonaparte basins (Thomas 1954b, 1957b; Thomas & Dickins 1954a). These and other significant works, such as the review of Western Australian Permian brachiopod faunas (Thomas 1969), have had major impacts on Late Palaeozoic Gondwanan and global correlations. George himself, with characteristic modesty, never trumpeted his achievements.

George was to continue his love of field work in Western Australia with extensive field seasons in the early to mid 1970s in the Carnarvon Basin. His particular target was the Early Permian Callytharra Formation, a richly fossiliferous unit. He was to measure and make extensive collections from 28 sections spaced out along the 300 km strike outcrop of the formation. Later field work (with Nancy) was carried out during the mid 1980s in the Canning Basin, in order to collect more fossil material from both the Noonkanbah and Hardman formations.

His palaeontological work was of the highest quality and demonstrated a rigorous respect for the literature and the importance of meticulous systematics, both aspects of the science that he endevoured, with infinite patience, to pass on to his students. He considered that it was essential to carry out systematic studies before publishing elaborate biostratigraphical schemes which would have little lasting value without the supporting descriptive analyses. His two systematic monographs (Thomas 1958b, 1971) are lasting monuments to the quality of his work. He was well aware of the need for direct comparison of his specimens with those from elsewhere and highlights were his examination of classic and new collections in Russia and the USA. His discussions with prominent brachiopodologists including such workers as Boris Konstantinovich Likharev, Elena Alekseevna Ivanova and Tat'yana Georgievna Sarycheva in Russia, and Gustav Arthur Cooper

Field work in the Carnarvon Basin, 1948

Field Camp, Carnarvon Basin, *c.* 1949

and Richard Evans Grant in the USA (amongst many overseas colleagues), were remembered with fond memories by George. He also remembered as great mentors senior colleagues in Australia including Curt Teichert, Armin Aleksander Öpik and Dorothy Hill.

George was a long-standing member of The Royal Society of Victoria and The Field Naturalists Club of Victoria. He joined the Geological Society of Australia in 1956 and the Association of Australasian Palaeontologists in 1976. He holds the record for being the longest serving secretary of the Victorian Division of the Geological Society of Australia (1963–1966, 1968–1969, inclusive). The break in 1967 was necessitated by his travel to the USA as a Senior Fulbright Scholar. He was also a member of the Paleontological Society (USA) and the Palaeontological Association (UK) and subscribed for many years to the Paleontologicheskii Zhurnal.

George, often with his family, travelled widely to Europe (including the then USSR), India, Asia and the Americas. These travels extended his range of geological friends, but were also opportunities to extend his wide cultural and historical interests. George's broad interests and knowledge were vast, as testified by a glance at the library in the family home at Ivanhoe. Lengthy discussions would range through philosophy, religion, and fine art, to subtleties of American Civil War history. However, above all, he was a family man and a true gentleman. His tolerance, patience and broad philosophy of life made him a great teacher, individual and friend. His was a life to celebrate and he shall be greatly missed by Nancy, his family and all who knew him.

VALE GEORGIVS

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APPENDIX: FOSSIL GENERA AND SPECIES NAMED IN HONOUR OF G. A. THOMAS

Some 10 fossil organisms have been named in honour of George A. Thomas. These include a genus and a subgenus of Permian brachiopods, four species of Permian brachiopods, one species of Carboniferous brachiopod, one species of Permian bivalve, one species of Tertiary ostracod and one species of Carboniferous shark. These are summarised below and the source references provided.

GENUS

Gatia Archbold 1993 Brachiopoda, Chonetida

SUBGENUS

Geothomasia Waterhouse 1998
Brachiopoda, Spiriferida

SPECIES

Nuculana thomasi Dickins 1956
Mollusca, Bivalvia

Yochelsonia thomasi Stehli 1961
Brachiopoda, Terebratulida

Podtsheremia? thomasi Roberts 1971
Brachiopoda, Spiriferida

Compressoproductus thomasi Cooper & Grant 1975
Brachiopoda, Productida

Svalbardia thomasi Archbold 1981
Brachiopoda, Chonetida

Stethacanthus (Cladodus) thomasi Turner 1982
Chordata, Chondrichthyes

Costiferina thomasi Archbold 1985
Brachiopoda, Productida

Polycope thomasi Warne 1990
Crustacea, Ostracoda

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Papers considered for publication may be: Reviews, Reports of experimental or descriptive research, or Short Communications. Length of papers may vary but Short Communications should not exceed 1500 words.

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All manuscripts should be written in clear and concise English. Use double spacing throughout; leave 30 mm margins around the text; number all pages. Underline only those words to be italicised in running text. All measurements are to be expressed in SI units (e.g. μm, mm, m, km, but not cm) and standard symbols used. Authors should follow the layout of headings, tables and illustrations as presented in a recent issue of the *Proceedings*. Papers should be organised as follows:

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2. *The name and address of the author(s)*, with superscripts to distinguish addresses of multiple authors.

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In taxonomic works, synonymies should be of the same format as the following examples, with a dash preceding authors' names except in the case of reference to the original description.

Eudendrium generalis Lendenberg 1885: 351, pl. 6.—Lendenberg 1887: 16.

Eudendrium generale.—Hartlaub 1905: 515.—Watson 1985: 196–200, figs 40–52.

non *Eudendrium generale.*—Watson 1982: 89, pl. 10, fig. 3.

Eudendrium lendenfeldi Briggs 1922: 150.—Rosler 1978: 104, 120, pl. 20, figs 1–3.

Note that plate and figure numbers, etc. originally given in Roman numerals should be transliterated into Arabic figures; this is also the case in the main text and in the references.

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7. *References.* These should conform in arrangement to the examples below, but do not type authors' names in capitals. Journal titles must be cited in full as they appear on the title page.

BIRCH, W. D., 1985. Calc-silicate rocks at Toolangi, Victoria. *Proceedings of the Royal Society of Victoria* 97: 1–18.

MACPHERSON, J. H. & GABRIEL, C. J., 1962. *Marine Molluscs of Victoria.* Melbourne University Press, Melbourne, xv+475 pp.

PARSONS, W. T., 1982. Weeds. In *Atlas of Victoria*, J. S. Duncan, ed., Victorian Government Printing Office, Melbourne, 122–125.

8. *Tables and Figures.* Each table with its title should be typed on a separate sheet. A separate sheet should also be used to list captions to figures in numerical order.

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PROCEEDINGS OF THE
ROYAL SOCIETY OF VICTORIA

Volume 113, Number 1

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